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☆ Mrs J. H. Schaefer.

26 June 1918.

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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

TELEGRAPHY

(VOL. II)

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CONTENTS

TELEGRAPHY.

(PART 4.)

TELEGRAPH REPEATERS.

1. A **telegraph repeater** consists of an arrangement of instruments and apparatus whereby signals coming over one line are repeated or sent forwards on another line by a separate battery. A common relay is really a repeater, for it causes the sounder in the local circuit to repeat the signals that pass through the relay coils. Thus, if the relay is placed midway between two end offices, and if the line on one side is connected to the relay coils and the line on the other side to the local contact points of the relay, it becomes a one-way repeater; that is, it will repeat in one direction. The simplest form of a repeater would consist of two relays, one for repeating in one direction and the other for repeating in the other direction.

2. Need of Repeaters.—As the length of a line increases, the working efficiency, which depends on the relation of insulation resistance to conductor resistance, decreases until it becomes so small that satisfactory signals cannot be transmitted no matter how much the battery power may be increased. Even if the insulation could be made sufficiently perfect, the line resistance would finally, as its length increased, become so great that it would require an electromotive force so high in order to force the necessary

current through the circuit that it would be neither safe, practical, nor economical. An electromotive force above 300 volts requires very good insulation of the line wire and also tends to develop a ground or leak at every weak point. Poorly insulated lines that may work fairly well with a low electromotive force may act as if permanently grounded at some intermediate station if too high an electromotive force is employed. Furthermore, if the resistance of the line could be kept small and the insulation sufficiently high, and an electromotive force of sufficient strength could be used, even then the electrostatic capacity of a long line would be so high that it would seriously diminish the speed of signaling. For, the time required for the current to become strong enough to affect the distant relay increases as the electrostatic capacity K increases, and if the resistance R also increases, as it usually does, with the length of the line, then the time increases as the product KR increases. This has been fully explained in preceding pages. On account of this retarding influence of the electrostatic capacity of the line and the inductance of the relay coils, both of which tend to delay the rise and fall of the current, the duration of contact at the distant relay is less than that at the sending key, thus causing a shortening of the signals and, hence, a reduction in the number of good signals that can be transmitted in one minute.

3. Firm or Heavy Sending Required.—On a very long line, very deliberate and firm, and, therefore, slower sending is required in order to get good signals on account of this retardation. In such a case, the whole line, neglecting the leakage to earth at the insulators, has to be charged and discharged through the end offices. Now, if this long line be divided into sections, each section charges and discharges independently of the others, and the sections being shorter than the whole line, it is evident that they will all be charged and discharged quicker than if connected in one continuous line. On a very long circuit with several repeaters, there would be a shortening of the signals at the far

end due to the fact that, as each circuit is closed, a short delay occurs in the transmission of a signal, because each armature has to move over a short distance from the rear to the front stop before the circuit is complete. This shortens the dots and dashes in proportion to the number of contacts to be closed, and thus the dots are sometimes wholly lost. Therefore, in operating a circuit containing one or more repeaters, the dots and the dashes should be made firm and longer, or as operators term it, the "sending should be heavy." The more repeaters there are in a circuit, the heavier should be the sending.

As a matter of fact and experience, the loss in speed due to this latter cause is not so great as is the gain in speed due to the quicker charging and discharging of the shorter sections into which the long line has been divided. Thus a long line can actually be worked faster and much more satisfactorily with repeaters than without, especially in wet weather, when the working efficiency decreases.

4. Distance Between Repeaters.—Moreover, it is possible to work long lines in this way, with wires of a reasonable size, fair insulation, and electromotive forces not unreasonably high, that could not be worked as one continuous line. In this country, with large and comparatively low resistance wires, it is not customary to operate, directly, a circuit over 600 miles in length. On well-insulated lines of good conductivity, and especially through dry regions, circuits are sometimes worked much longer distances without repeaters.

The line from San Francisco to New Orleans, a distance of 2,484 miles, is now being worked with only one repeating station, which is at El Paso. This repeating station is even cut out occasionally and the line worked direct. The long stretch of country through Arizona, New Mexico, and Western Texas is unusually well adapted to long-distance telegraphy, the atmosphere being dry and rare. The atmospheric conditions along the California coast and in the swamps of Louisiana and Eastern Texas, through

which the remaining portion of the line runs, are not favorable for long-distance telegraphy, but this has been overcome by using copper line wire and by taking good care of the insulators.

Another long line, that from Montreal to Vancouver, a distance of 2,898 miles, was to be worked, according to last reports, with two equally distant repeating stations. It is quite likely that during part of the year only one repeater will be required. The line will be worked duplex, and, later, if business increases sufficiently, it will be quadruplexed. The entire line consists of hard-drawn copper wire, weighing 300 pounds per mile.

5. Long Circuits Worked by Use of Repeaters.—By the use of repeaters it is possible to work to very great distances. A line from London to Teheran, a distance of 3,800 miles, is worked directly by the aid of five automatic repeaters. In this country, on April 25, 1899, the Associated Press combined its circuits, and formed a line 6,000 miles in length. The matter transmitted from New York for several hours was received in all the leading cities, requiring the services of 41 operators in all.

BUTTON REPEATERS.

6. Repeaters, requiring that a button, or switch, be turned manually by an attendant, in order to change from repeating in one direction to repeating in the opposite direction, are usually called **button repeaters,** and, occasionally, **manual repeaters.** With such repeaters an operator must listen to what is passing and be ready at any moment to turn over the button, or switch, in order to reverse the direction in which messages may be sent and so allow the operator at the receiving end to send, and *vice versa.* A button repeater, since it requires the constant attendance of an operator, is generally employed for temporary purposes only.

THE WOOD BUTTON REPEATER.

7. The arrangement of the Wood button repeater is shown in Fig. 1. M is a switch so arranged that the lever k, which is pivoted at the center, is always in contact with one or both of the brass pieces c and d; o, o_1, o_2, and o_3 are binding posts, each joined to the respective brass pieces a, b, d, and c; g is a ground switch connecting the lever k of the switch M with the ground at G; W is the western and E

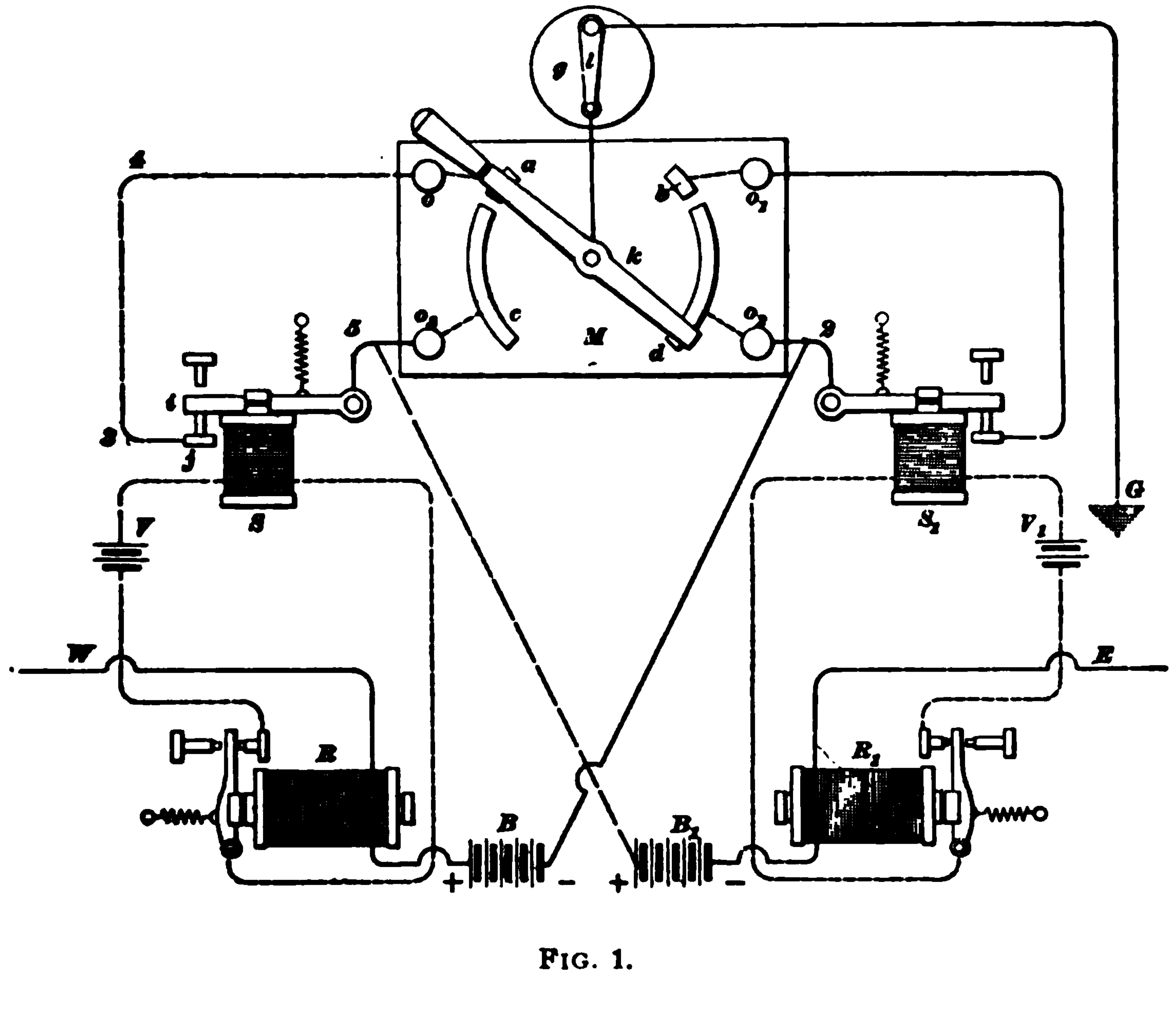


FIG. 1.

the eastern main line; R and R_1 are the western and eastern relays; S and S_1 the western and eastern repeating sounders, and B and B_1 the western and eastern main-line batteries. B and B_1 *must be arranged in series*, the plus pole of one being connected to the minus pole of the other, for this arrangement allows the line to be connected straight across, as will be explained later. V and V_1 are local batteries.

8. Operation.—If the ground switch g is closed and the lever k is placed so as to connect d with a, the western circuit will repeat into the eastern. If the western key is closed, a current proceeds from the plus pole of battery B, goes through the relay R, then to the western station, where the line is grounded, back through the earth to G, through lever l to lever k, to d, o_2, 2, and to the minus pole of battery B. By this current, relay R is caused to close its local circuit, which causes sounder S to close the circuit of battery B_1. This circuit may be traced as follows: From the plus pole of battery B_1 through 5, i, j, 3, 4, o, a, lever k, through lever l to the earth at G, then through the earth to the eastern station and back through the eastern relay R_1 to the negative pole of B_1. The sounder S repeats the message and the relay R_1 operates the sounder S_1. No circuit is closed, however, by the armature of the sounder S_1, as there is a break between b and k. It, therefore, acts merely as a reading sounder.

If the lever k be placed so as to connect c with b while switch g is closed, the eastern circuit will repeat into the western, and the circuits may be traced as before, beginning, however, with eastern line and battery B_1. The single ground at G will serve for both eastern and western circuits.

If the lever k connects c and d and switch g is opened, the eastern and western circuits are connected straight across. This circuit is as follows: From the plus pole of battery B, through relay R to the western station, through the earth to the eastern station, then to relay R_1, and to the minus pole of battery B_1. Batteries B and B_1 are connected as one battery in series through 5–o_1–c–k–d–o_2–2.

If k connects c and d, and switch g is closed, two independent circuits are formed, namely, B–R–W–G–l–k–d–o_2–2–B and B_1–5–o_1–c–k–l–G–E–R_1–B_1.

9. In this arrangement, if the two sounders do not work in unison, the lever k must be instantly turned by the operator in attendance, so that the person receiving may be able to break and become the sender.

MODIFIED WOOD BUTTON REPEATER.

10. A modified form of the Wood button repeater that is also used is shown in Fig. 2. No provision is made in this arrangement for connecting the circuits straight across. This is not necessary in a repeater, because such connections can be made directly at the switchboard, including an ordinary relay in the circuit if desirable.

When the switch M is turned to the left, the switch blade connects c with d and the eastern circuit will repeat into the western. In this position the east line cannot be opened at the repeater station by any action of the sounder S_1.

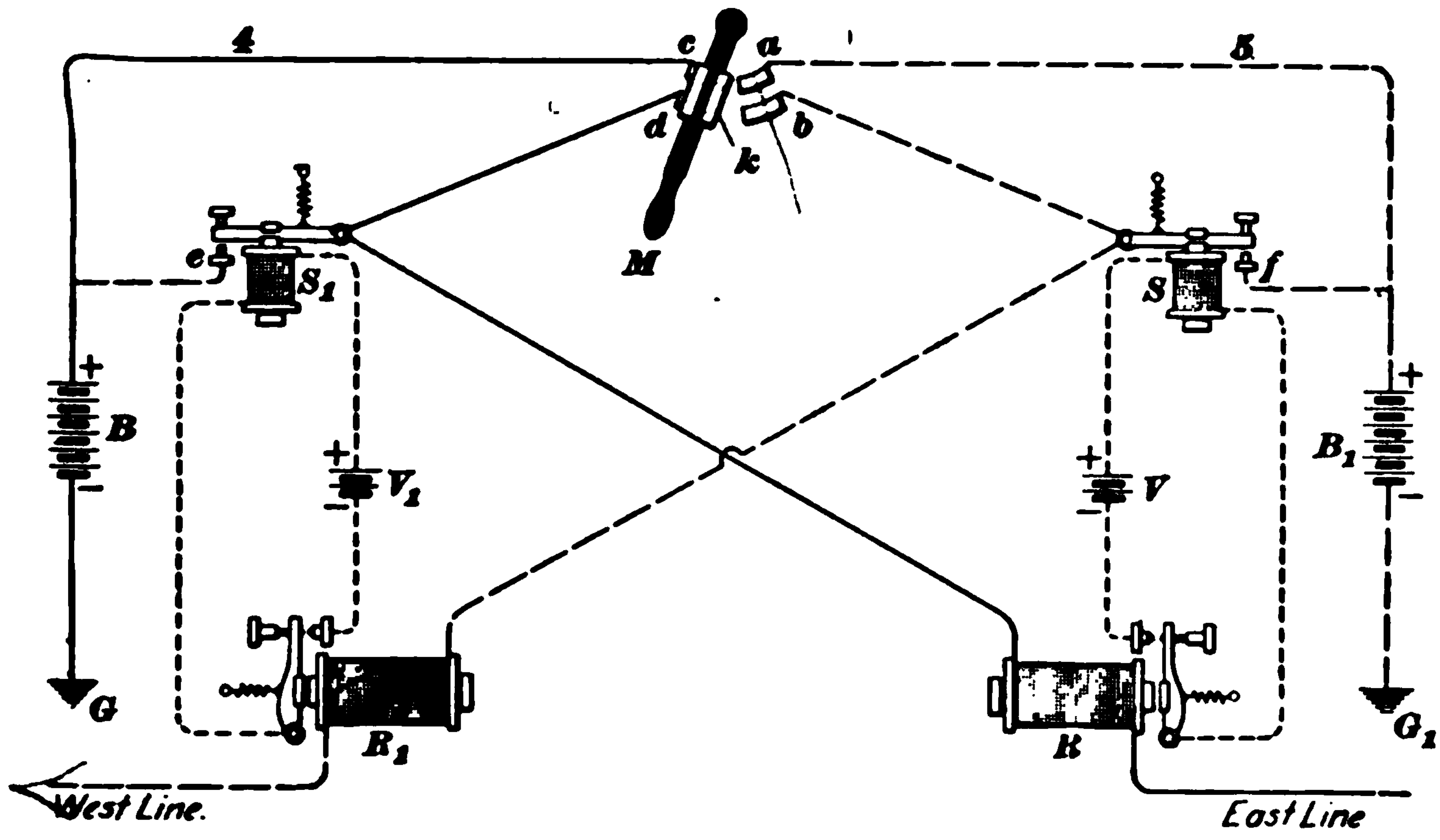


FIG. 2.

When the switch M is turned to the right, the switch blade k connects a with b and the western circuit will repeat into the eastern. In this position it is impossible for the operator at the western office to open the western circuit at the repeater station.

When the switch M is in the center position, the blade connects c with d and a with b and two independent circuits are formed; namely, G–B–4–c–d–R–east line to eastern office and back through the ground to G, and G_1–B_1–5–a–b–R_1–west line to western office and back through the ground to G_1.

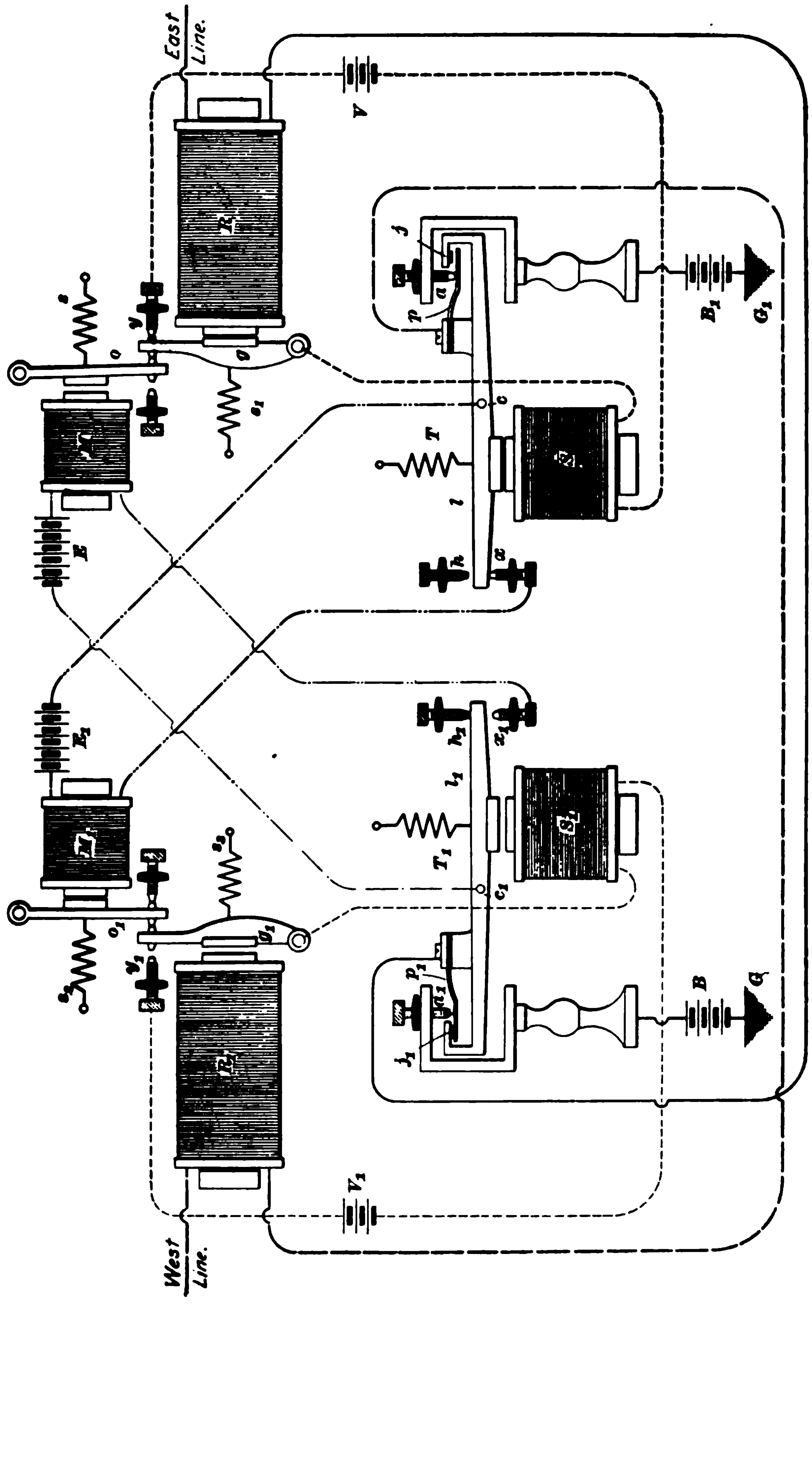


FIG. 3.

The operation of this repeater, outside of the changes in the connections that can be made by means of the switch M, is precisely the same as in the Wood repeater previously described, so that an explanation of its operation in the act of repeating seems to be unnecessary.

AUTOMATIC REPEATERS.

11. An **automatic repeater** is one that will *automatically repeat* in *either direction* without the necessity of turning a switch. An operator, however, is always needed to adjust the armatures of the relays and sounders, and to care for the batteries, but, of course, his time may be largely devoted to other duties.

MILLIKEN REPEATER.

12. The **Milliken repeater,** although one of the earliest automatic repeaters used in telegraphy, is still regarded in the United States as the standard repeater; it is shown in Fig. 3. R and R_1 are main-line relays mounted on metal standards that hold them rigidly in place with respect to the extra magnets M and M_1. The levers of the relays and extra magnets are pivoted, as shown in the figure; the springs s and s_2 are so much stronger than s_1 and s_3 that the levers g and g_1 are pressed against the contacts y and y_1 when there is no current in either R or M, nor in R_1 or M_1, respectively. The telegraph instruments T and T_1 are called *transmitters.* When current flows through the electromagnet S, the armature lever l is attracted, causing the insulated spring, or *tongue* p, as it is called, to come into contact with the stop a slightly before the other end of the lever l touches x. When the current stops flowing through the coil of the transmitter, the lever is released, as shown at T_1, causing the contact at x_1 to be broken slightly before the contact is broken at a_1. The bent-over ends of the levers of the transmitters may or may not be tipped with

insulating pieces j and j_1. B and B_1 are main-line batteries, V and V_1 local batteries, and E and E_1, so-called extra local batteries.

13. Normally, all circuits are closed. The western main-line circuit may be traced from the western office through R_1–p–a–B_1–G_1 and the ground back to the western office. The eastern main-line circuit is from the eastern office through R–p_1–a_1–B–G and through the ground back to the eastern office. The local circuit of R_1 includes V_1–y_1–g_1–S_1, and the local circuit of R includes V–y–g–S. The extra local circuits, including the magnets M and M_1, are, respectively, M–x_1–l_1–c_1–E and M_1–x–l–c–E_1.

14. Operation.—Suppose that all circuits are in their normal condition, that is, closed. If, now, the western key is opened, the relay R_1 will lose its magnetism, but the magnet M_1 retains its magnetism; hence, the armature g_1 is released by the relay magnet and is not held by the spring s_2; therefore, it breaks the local circuit between g_1 and y_1, causing the lever l_1 of the transmitter T_1 to first break at x_1 the extra local circuit containing M, and then to break the eastern main-line circuit between p_1 and a_1. Thus M is first demagnetized and the spring s presses the lever o against the lever g, so that when a moment later R is also demagnetized by the opening of the circuit between a_1 and p_1, the lever g is still held against y, since the spring s is adjusted to overcome the pull of the spring s_1. Thus, the opening of the circuit containing the electromagnet S of the transmitter T is prevented. The opening of this circuit, when the western circuit is repeating into the eastern circuit, would be fatal to the successful operation of the repeater. Therefore, when the western key is opened, the eastern circuit is opened without opening the western circuit at the repeating station. In the figure, the instruments are shown in their proper position when the western key is open.

15. The chief function of an automatic repeater is to automatically prevent the opening or breaking of the sending

circuit at the repeater station. For instance, the transmitter that controls the western circuit must not open the western circuit at the repeating station when the western circuit is repeating into the eastern circuit. The *opposite transmitter*, a term frequently used, may be defined as being the one controlled by the relay in the circuit that is being repeated into. For instance, when the western circuit is repeating into the eastern circuit, the transmitter T is the opposite transmitter, because it is controlled by the relay R in the opposite circuit, and this transmitter T must remain closed while the western is repeating into the eastern circuit.

16. When the western key is again closed, the circuits are closed between g_1 and y_1, between p_1 and a_1, and between l_1 and x_1 in the order named. Thus a signal is sent into the eastern line by the closing of the eastern circuit between p_1 and a_1 and, therefore, the western circuit repeats into the eastern. To repeat from the eastern into the western circuit, the foregoing actions are reversed.

The attendant, if necessary, can read the signals from the sound made by the lever l, or l_1. If it is desirable to know just how the signals are being transmitted through the main-line circuits, a relay controlling a local sounder may be cut into either main-line circuit by inserting a double wedge, to the two sides of which the relay is connected, into either line jack at the switchboard.

17. Side-Line Repeater.—A side-line repeater is one that has been arranged to repeat from a through main line into a line branching off from the repeating station. The Milliken repeater can readily be used for this purpose. Suppose, for instance, that there was a through line from New York to Buffalo, and that it was desirable to send the same message to Syracuse by means of a Milliken repeater at Elmira. Suppose, further, that the eastern line in Fig. 3 is the one coming from New York. The battery B in this line may or may not be removed, but the line, instead of being grounded at G, would extend to Buffalo, where it would be grounded after passing through a relay and battery. The

side line circuit would run from the ground G_1 through B_1–a–p–R_1 at Elmira through the west line in this figure to Syracuse. Thus the message passing over the main line from New York to Buffalo would be repeated into the side line running from Elmira to Syracuse. Furthermore, any one of the three operators located at New York, Buffalo, or Syracuse could send while the other two received.

18. The Milliken repeater is considered one of the best repeaters made, and its operation is entirely satisfactory. It requires, however, more local batteries than almost any other repeater, is not so easy to keep properly adjusted, and the extra local batteries must be kept in exceptionally good condition.

19. Repeater Relay and Extra Magnet.—In Fig. 4 is shown the repeater relay and extra magnet commonly listed and sold as the **Milliken-Hicks repeater.** The relay R is adjusted in exactly the same manner as an ordinary relay

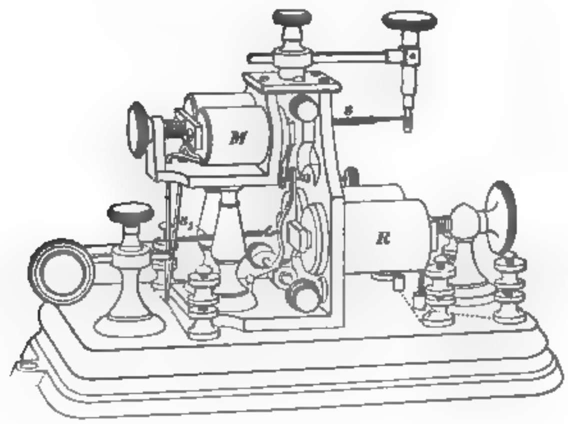


FIG. 4.

and the extra magnet M will seldom need readjustment if the extra local batteries are kept in good condition. The spring s must be slightly stronger than the spring s_1 and the armature of the magnet M must have no more movement than is necessary to allow the circuit to be opened.

20. Transmitter.—In Fig. 5 is shown one form of transmitter. The dotted lines show the connections between the binding posts in view and the stop-screw *a* and the tongue *p*. The tongue *p* is fastened to a piece of insulating material *i* that is in turn secured to the lever *l*. When used as part of a Milliken repeater, this transmitter has the lower end of the screw *h* tipped with insulating material. Some Milliken transmitters have two simple switches mounted on the base. When closed, one connects (see Fig. 3) *x* with *c* and the other connects *p* with a wire running to the positive pole of B_1. When all four of these switches (two on each

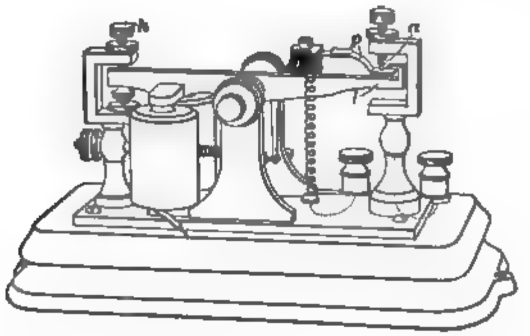
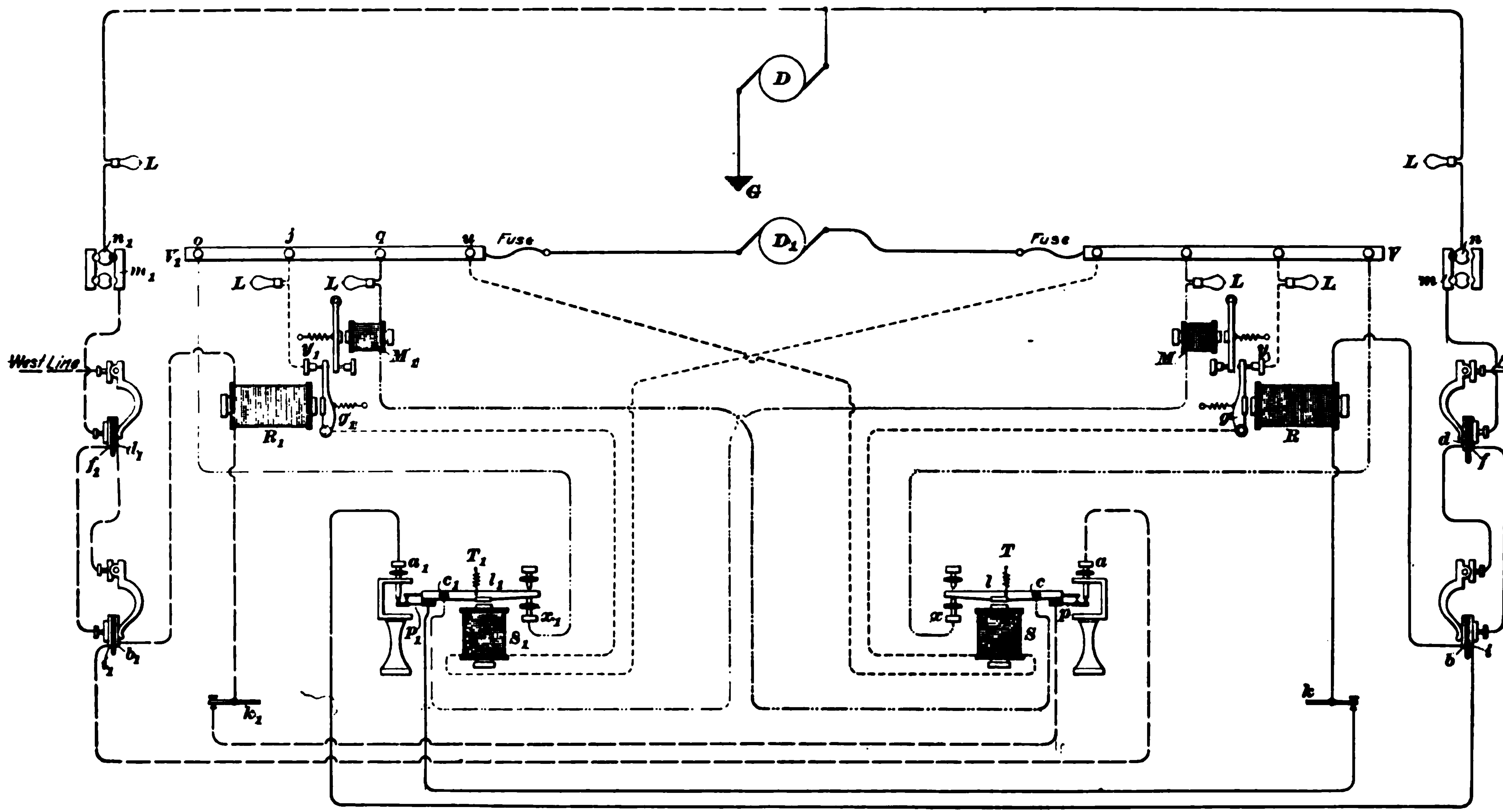


FIG. 5.

transmitter) are closed, the two extra magnets, including their local batteries, are on closed circuit and so hold their armatures *o* and o_1 permanently away from the relay armatures *g* and g_1, thus allowing the relays *R* and R_1 to operate as simple relays. Furthermore, the east and west lines are permanently closed by being shunted around the contact points of the transmitters to their respective main-line batteries and to the ground, and so prevent the movement of the transmitter levers from opening either the east or west line. Thus, each side of the repeater may be used as an independent circuit.

21. Adjustment of Transmitters.—The lever of the transmitter, or sounder, as it is sometimes called, should have, in order to secure good connections at the



D
G
D_1
Fuse
Fuse
West Line
East Line
L
L
L
L
L
L
n_1
m_1
n
m
V_1
o
j
q
u
V
M_1
M
R_1
R
T_1
T
S_1
S
a_1
a
c_1
c
l_1
l
x_1
x
p_1
p
f_1
l_1
b_1
k_1
k
d
f
b

FIG. 6.

contact points, only movement enough to break the circuit, and the spring should be adjusted to have a very moderate tension, only a little more than enough to raise the lever when released by the magnet. The lever should have a play of about $\frac{1}{32}$ inch.

It often happens that the signals will pass through the repeater all right and yet be positively unreadable at the distant office, causing considerable misunderstanding between the operators at one end and at the repeater station. This is due to an improper adjustment of the transmitter contact points, due to the fact that the tongue p does not break contact, as it should, at the instant when the other end of the lever is exactly midway in its travel between the lower and upper stops. This incorrect adjustment causes the tongue to cling too long to one point and not long enough to the other. The signals will be too light, that is, too short, if the duration of contact between the tongue p and lever l, as the tongue end of the lever moves up, is too long, due to a being too high; and the signals will be too sluggish, heavy, or long if the duration of contact between p and a, as the tongue end of the lever moves down, is too long, due to a being too low. Therefore, a should be adjusted to break just as the lever passes through the horizontal position and is midway in its travel; causing the *duration of contact between p and a and between p and l to be equal.* These remarks will apply to the adjustment of all forms of transmitters wherever used, unless something to the contrary is mentioned.

22. Milliken Repeater Operated by Dynamos. In Fig. 6 is shown the actual connections of the Milliken repeater when the main and local circuits are all supplied with current from dynamos. In this case, one machine D_1 supplies the four local circuits and another D the two main-line circuits. The lamps L, L, etc. are of suitable resistance to allow the necessary current to flow in each circuit. The two main-line circuits from the repeater go to wedges $b\,i$ and $b_1\,i_1$ at the loop switch, then by "flying" loops to

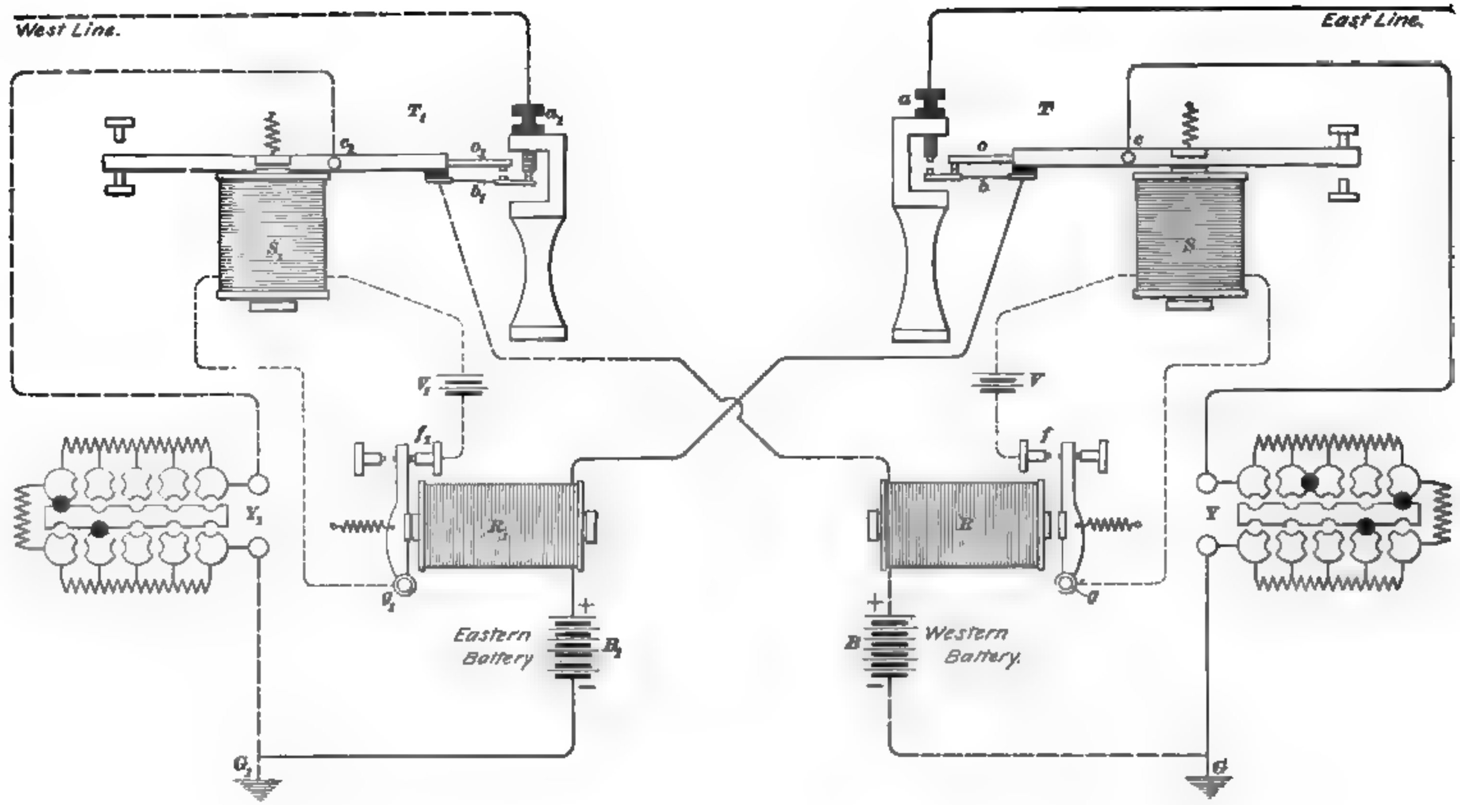


FIG. 7.

wedges df and $d_1 f_1$ at the main switch; one side of each circuit then goes to a line, the other side through vertical straps m and m_1, pin plugs, disks n and n_1, lamps L, L, dynamo D, and, finally, to ground G. Keys k and k_1 are included in the main-line circuits in order to enable the attendant at the repeater office to communicate with either of the two distant operators. The six circuits may be traced out as follows: West line to d_1-b_1-R_1-k_1-p-a-i_1-f_1-m_1-n_1-L-D-G back through the ground to the western office and line; east line to d-b-R-k-p_1-a_1-i-f-m-n-L-D-G back through the ground to the eastern office and line; the extra local circuits D_1-V_1-o-x_1-l_1-c_1-M-L-V-D_1, and D_1-V_1-q-L-M_1-c-l-x-V-D_1; and the local circuits D_1-V_1-j-L-y_1-g_1-S_1-V-D_1, and D_1-V_1-u-S-g-y-L-V-D_1.

The operation of this repeater, when supplied with current from dynamos, as shown in the figure, is exactly the same as has already been explained in connection with Fig. 3, where primary batteries were used; and, consequently, the student should readily understand this one without further explanation. All circuits are shown in their normal, or closed, position, and a newer type of transmitter is represented in this figure.

TOYE REPEATER.

23. The **Toye repeater,** which is quite extensively used in the United States, and especially in Canada, is very simple indeed, as will be seen from the diagram given in Fig. 7. The only apparatus necessary in connection with this repeater that has not already been considered are two adjustable resistance boxes Y and Y_1. These are adjusted, as indicated, by means of brass pegs that may be inserted in holes between brass disks in order to cut out one or more of the resistance coils. The resistance in Y must be kept about equal to the resistance of the eastern circuit from the point a to the ground at the eastern office, and the resistance in Y_1 must be kept about equal to the resistance of the western circuit from a_1 to the ground at the western office. R and R_1

are ordinary relays, and T and T_1 are standard transmitters. B and B_1 are the main-line batteries and V and V_1 the local batteries. The connections are so clearly shown that it seems unnecessary to enumerate the various circuits. The principle of this repeater consists in holding the sending circuit closed at the repeater *by substituting in the place of the receiving line at the instant the latter is opened, a resistance equal to the receiving-line circuit*, thus keeping the relay and transmitter that control the sending line closed.

24. Operation.—Suppose all circuits to be closed. Then, a_1 presses against tongue b_1 and holds the circuit open between b_1 and o_1; and, similarly, a makes contact with the tongue b and keeps b and o separated. When the western operator opens his key, there will be no current from the western office through a_1–b_1–R–B–G. This will allow R to demagnetize and open the local circuit V–S–g–f at f, and, in turn, allow the transmitter T to open the eastern circuit at a; but just the instant before the tongue b separates from a it touches o, and, thus, the current, which previously flowed from B_1 through R_1–b–a to east line and through the ground to G_1 and back to B_1, now flows from B_1 through R_1–b–o–c–Y–G to ground to G_1 and back to B_1. These two circuits being of equal resistance and the rheostat circuit Y being instantly substituted for the eastern circuit by the opening of the transmitter T, the relay R_1 is not only not demagnetized, but the strength of the current remains the same, and, consequently, the *local circuit of the relay R_1 is kept closed and the western circuit is therefore not opened* at a_1. When the western key is closed, current again flows through R, and then through S, and all circuits are again closed, which is their normal state. Thus the western circuit repeats into the eastern. To repeat from the eastern into the western circuit, the foregoing actions are reversed.

25. The special advantages of this repeater are its extreme simplicity and the fact that it requires comparatively few pieces of only standard apparatus, namely,

standard transmitters, relays, and rheostats. However, this repeater is very severe on the main batteries, for they are kept closed all the time. Furthermore, each rheostat must be kept adjusted so that its resistance is about equal to that of the main-line circuit which it replaces, otherwise the difference in the magnetic strength of the relay, due to shifting the battery circuit from the line to the rheostat, may throw the relay out of adjustment and so open one of the circuits at the transmitter that the relay controls.

This means that for efficient service, every change in the weather or resistance of the wire will require an alternation in the value of the rheostat in addition to the usual care of the relay itself, a feat not easily accomplished in extreme weather or on a wire from which there is very much leakage.

26. The Toye repeater is adjusted by varying the resistance in the rheostat until the magnetic pull of the relay is the same whether its circuit is closed at the opposite transmitter through the line or the rheostat. The Toye repeater, without modifications, is not suitable for a side-line repeater, nor is it as satisfactory for all-around work as the Milliken, the Neilson, or the Weiny-Phillips, and perhaps some other modern types. Where a number of short lines have approximately the same resistance, such as the duplex loops, or legs, in the larger cities, the Toye repeater, slightly altered and called the *defective loop repeater*, gives excellent service as a side-line repeater.

27. Bunnell Transmitter.—A form of transmitter made by Bunnell & Co. that may be used in the Toye and other repeaters, and in some multiplex systems, is shown in Fig. 8. The tongue *b* is fastened to a piece of insulating material *i* that is in turn secured to the lever *c*. When the magnet releases the

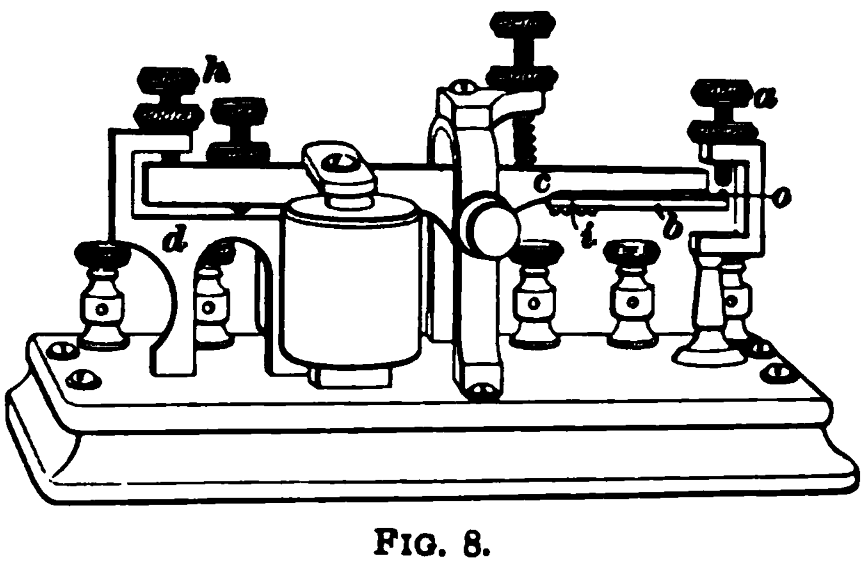


FIG. 8.

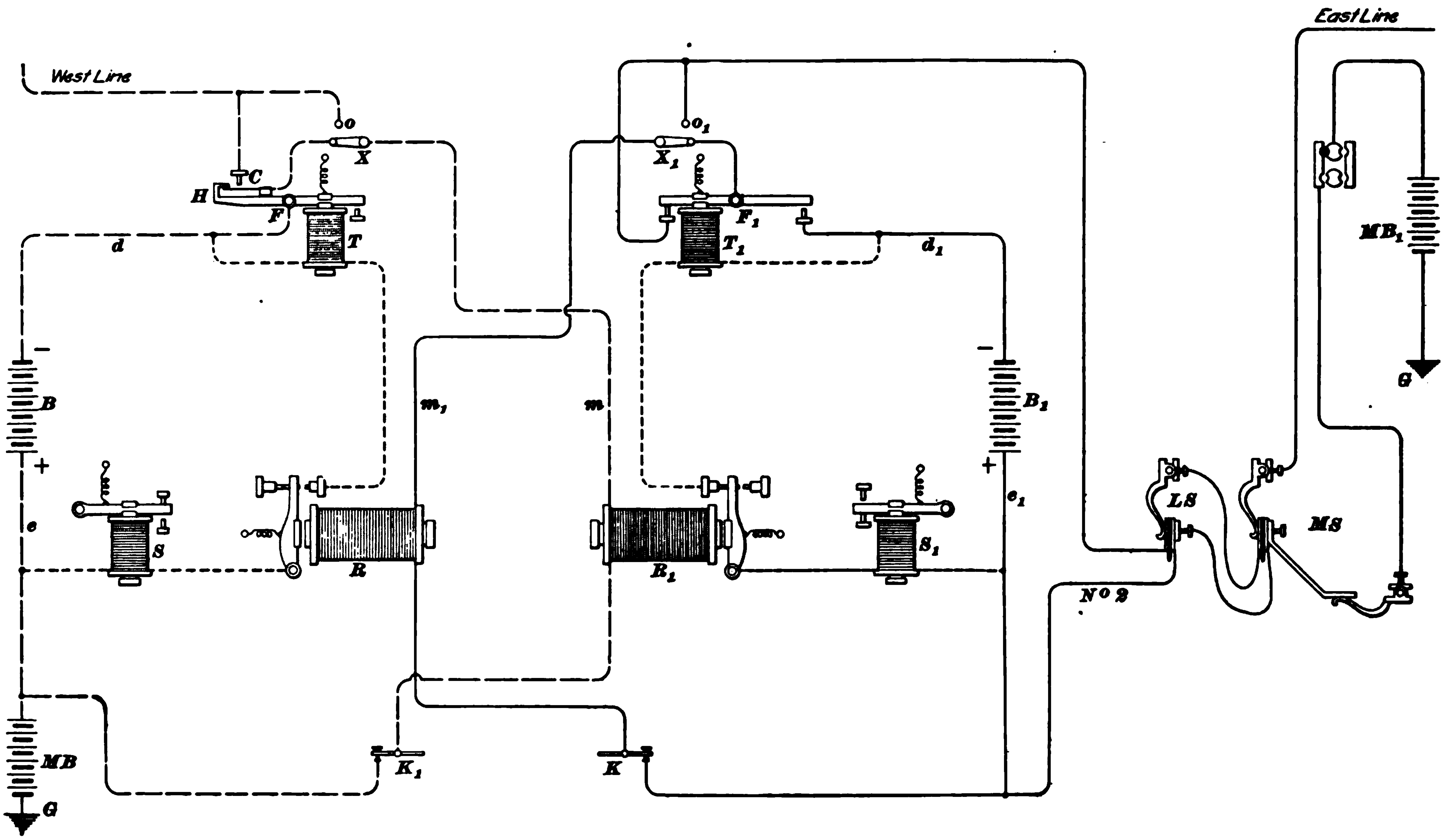

West Line
East Line
o
X
C
H
F
T
d
o_1
X_1
F_1
T_1
d_1
MB_1
G
B
B_1
m_1
m
e
e_1
S
R
R_1
S_1
LS
MS
No 2
MB
G
K_1
K

FIG. 9.

armature, a metal contact point on the end of the lever *c* comes in contact with the tongue *b* and presses the latter away from the contact screw *a*. When the armature is attracted by the magnet, the tongue *b* touches the screw *a* just before the contact point on the tip of the lever separates from the tongue *b*. It is, therefore, a continuity-preserving transmitter because one circuit is closed before the other is opened. *a*, *b*, and *c* are connected to separate binding posts on the base of the instrument.

If this transmitter is used in the *Atkinson* repeater, which will be described presently, it is only necessary to insulate the tip of the screw *h* so it cannot make a metallic contact with the lever *c*, and, also, to connect *d*, which corresponds to *d* in the diagram for the Atkinson repeater (see Fig. 16), to a separate binding post upon the base.

MODIFICATION OF THE TOYE REPEATER.

28. The repeater illustrated in Fig. 9 was explained in "The Telegraph Age" of July 16, 1900, by Mr. R. J. Hewett. Although the rheostat, the distinctive feature of the Toye, is eliminated, still it is called a modification of that repeater. All that is necessary to fit out a full set of repeaters are two common relays R and R_1, two transmitters, or two pole changers, or one transmitter and one pole changer T and T_1, two 2-point table switches X and X_1, two keys K and K_1, and two auxiliary batteries B and B_1 of about 7 cells each. Two sounders S and S_1 had better be used as reading sounders, for their use will allow the transmitters to be adjusted closely, so as to reduce their mechanical lag to a minimum.

"Pole changers may be used instead of transmitters. This is shown on the right of the diagram. The stroke of the pole changer T_1 should, however, be shorter than when it is used in regular quadruplex service, so as to reduce the no-current interval, which occurs when the lever F_1 of the pole changer is moving from one position to

another, to a minimum; and, since the no-current interval is, in this case, not accompanied by a reversal of current, as in regular quadruplex service, there is no excessive sparking and no difficulty in maintaining a close adjustment. It, therefore, makes a very close breaking repeater, being equally as close as the Neilson repeater."

The keys K and K_1 enable the attendant at the repeater office to communicate with either of the two distant operators. The switches X and X_1 are in the proper position in the diagram for the use of the apparatus as a repeater. When these switches rest on the contact buttons o and o_1, the relays, sounders, and keys constitute two independent office sets. The eastern circuit is shown connected through the loop switch $L S$ and the main switchboard $M S$, one wire being connected to the east line and the other wire through the main-line battery $M B_1$ to the ground G. The western circuit would be connected through a loop, main switch, west line, and battery in the same manner. The switchboard loop must always connect to the main line in such a way as to have the polarity of the auxiliary battery B_1 agree with the polarity of the main battery $M B_1$, otherwise there will be a reversal of the current through the relay R when the transmitter or pole changer T_1 opens, and this would cause a kick, or break, in the signals. The kick would result in a vibration of the lever of the relay R. When this occurs, it is only necessary to reverse the wedge at the switchboard to correct the trouble.

29. As a makeshift, ordinary box relays may be used in place of the transmitter or pole changer. For this purpose, the insulated back contact is supplied with a platinum point, and a third binding post is provided for it. The reading sounder is then omitted, as it cannot be worked in circuit with the high-resistance box relay.

30. Operation.—Suppose the eastern operator opens his key; then the relay R opens its local circuit, allowing the sounder S and transmitter T to release their armatures and the hook end H of the transmitter T descends

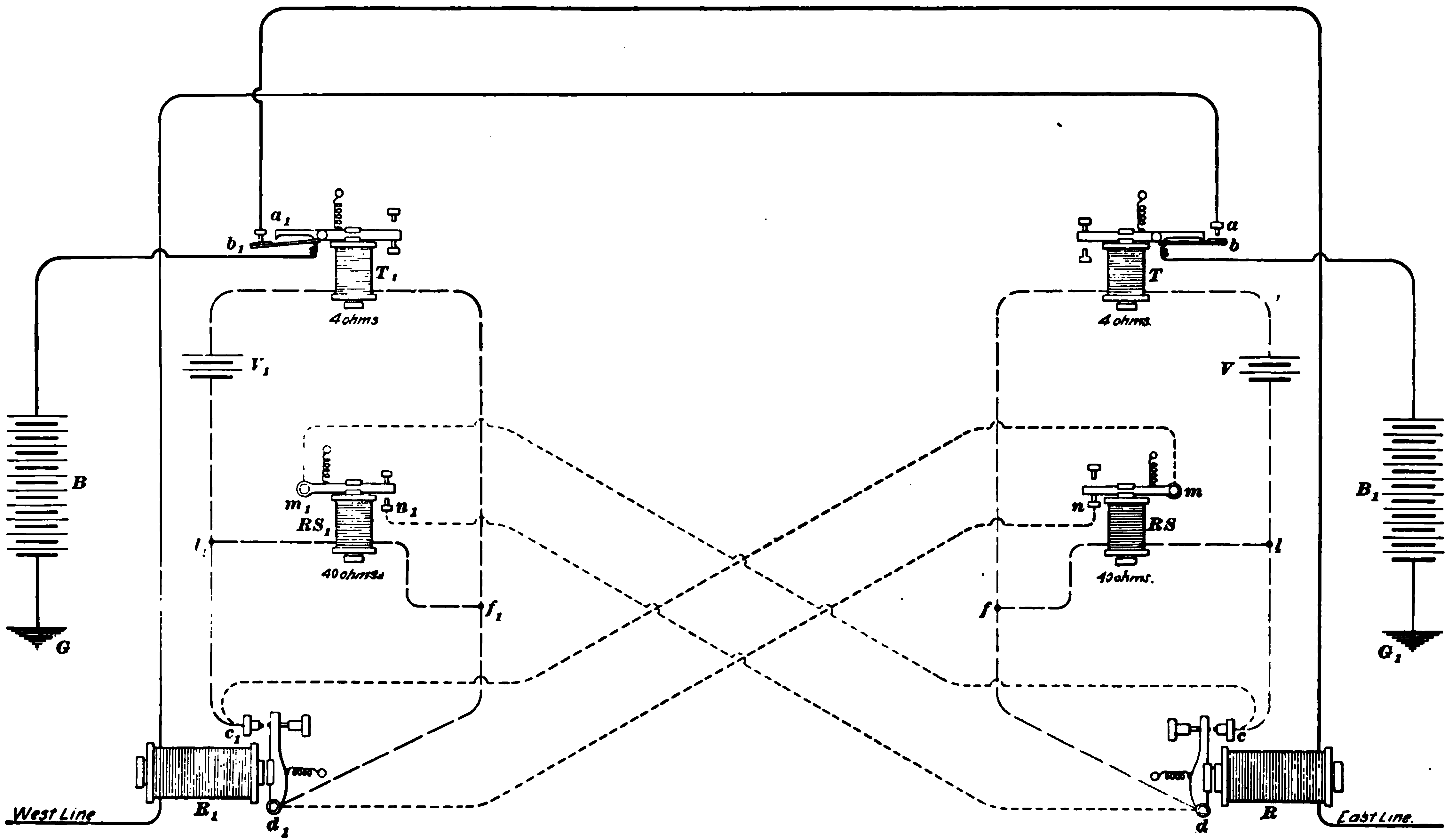
and carries with it the spring tongue, thus breaking contact with the stop C and opening the west line. At the same time that the west line is opened at this contact stop C, the spring tongue makes connection with the hook H, as previously explained, and this connects the auxiliary battery B in a closed circuit containing the relay R_1, key K_1, wire c, battery B, wire d, transmitter lever F, hook H, spring tongue, switch X, and wire m. The relay R_1 is thus held closed, and, consequently, T_1 will be held closed and inactive, and thus prevent breaking back into the sending side.

31. When the circuits are idle, the auxiliary batteries supply current to their transmitters and sounders in the usual way, but when the circuits are working, the auxiliary battery on the sending side will supply current to the relay on the receiving side and hold it closed whenever the receiving side is opened at the transmitter. The auxiliary battery is thus on closed circuit all the time, either on its transmitter and sounder circuit or on the opposite relay. This is all right for gravity cells, because it is better to have them closed too much rather than too little of the time. Having them closed the entire time, however, means considerable consumption of battery material.

NEILSON REPEATER.

32. The **Neilson,** or **Neilson shunt repeater,** as it is also called, has given entire satisfaction in Canada. It has an advantage over some other repeaters in that it only requires one local battery for two magnets. It may also be used as a side-line repeater.

In Fig. 10, in which is given the diagram of connections for the Neilson repeater, R and R_1 are ordinary relays; RS and RS_1, repeating sounders, each of 40 ohms resistance; B and B_1, the main-line batteries; V and V_1, the local batteries; and T and T_1 are either ordinary transmitters or repeating sounders, each of 4 ohms resistance.



a1
b1
T1
4 ohms
V1
B
m1
RS1
n1
l1
40 ohms
f1
G
c1
West Line
B1
d1
a
b
T
4 ohms
V
m
n
RS
l
40 ohms
f
B1
G1
c
R
d
East Line

FIG 10.

33. When current flows in the two main-line circuits, the armatures of the relays R and R_1 hold the local circuits closed at c and c_1 and, consequently, currents flow through the two local circuits $V-T-f-d-c-l-V$ and $V_1-T_1-f_1-d_1-c_1-l_1-V_1$. These currents energize the transmitters T and T_1, and keep the two main-line circuits closed at the contact points of the transmitters, the eastern circuit being closed at b_1 and the western at b. In this condition the magnet coils of the repeating sounders RS and RS_1 are short-circuited or shunted by the relay armatures, which have practically no resistance when compared to the 40 ohms in the repeating sounders, and, therefore, practically no current flows through the repeating sounders. Consequently, the contact points n and n_1 at the repeating sounders are normally open. In this condition of the local circuits, the transmitters get $\frac{2}{4+4} = \frac{1}{4}$ ampere, assuming each cell to have an electromotive force of 1 volt and an internal resistance of 2 ohms.

Suppose the circuit through the relay R is opened; then its armature opens the circuit at c, thus removing the short circuit around RS and leaving the transmitter T and the repeating sounder RS in series. The current from V will now flow in the circuit $V-T-f-RS-l-V$. The current in this circuit is $\frac{2}{40+4+4} = \frac{1}{24}$ ampere, which is not enough to keep the transmitter T closed, but is sufficient to close the 40-ohm repeating sounder RS because it has so many more turns of wire in its coils than there are in the 4-ohm transmitter coils.

If, with T open and RS closed, the repeating sounder RS_1 on the other side should by any means close, RS would be again short-circuited, although this time through $f-d-n_1-m_1-c-l$, instead of through $f-d-c-l$, as before. Still the result would be the same; RS would open and enough current would flow through the transmitter T to close it. This must not occur; that is, RS_1 must not close nor RS open while the eastern key is open; and, furthermore, RS_1 must never close while the eastern circuit is repeating into the western.

34. Operation.—The two main circuits will normally be closed, causing the two transmitters to be closed and the two repeating sounders to be open. Suppose the eastern key is opened. There now being no current through the relay R, it will release its armature and thus open the short circuit around $R\,S$ at c. This will leave the repeating sounder $R\,S$ in series with the transmitter T, causing $R\,S$ to close and T to open at the same moment. The opening of T opens the western circuit at a, allowing R_1 to demagnetize, and to open its local circuit at c_1. Furthermore, as soon as T opened, the repeating sounder $R\,S$ closed, thereby closing the short circuit f_1–d_1–n–m–c_1–l_1 around $R\,S_1$, thus preventing the closing of $R\,S_1$ or the opening of T_1, and so preventing the opening of the east line at b_1. Thus, when the eastern key is opened, the east-line circuit is not opened at the repeater. When the eastern key is closed, current will flow from the positive pole of B through b_1–a_1–R to east line, to the eastern office, the ground, and back through the ground to G and to the negative pole of the battery B. This will energize R and so close the local circuit at c, allowing $\frac{1}{4}$ ampere to flow through the circuit V–T–f–d–c–l–V and causing T to close the west-line circuit at a. The repeating sounder $R\,S$, being short-circuited by the armature of the relay R, loses its magnetism and, consequently, opens at n the short circuit f_1–d_1–n–m–c_1–l_1, around $R\,S_1$, but at the same instant, since R_1 is now magnetized, the other short circuit, f_1–d_1–c_1–l_1, around $R\,S_1$ is closed at c_1. Thus the current through T_1 remains the same, $\frac{1}{4}$ ampere, and T_1 is kept closed and $R\,S_1$ open, that is, demagnetized, no matter whether the east line is open or closed. Consequently, the transmitter T_1 remains closed all the time that the eastern circuit is repeating into the western—the essential feature of a repeater.

To repeat from the western into the eastern circuit, the above operations are reversed. In this repeater, the local batteries are closed all the time and furnishing the maximum current, $\frac{1}{4}$ ampere, except when the eastern or western key is open in the act of sending a space.

35. Repeating Sounder. By providing an ordinary sounder with contact points, so that the movement of the lever opens and closes a second circuit entirely distinct from the circuit containing the sounder coils, we have a repeating sounder. Such a repeating sounder, often called the **quadruplex repeating sounder** because it was probably first used in quadruplex systems, is shown in Fig. 11. It is similar to the ordinary sounder made by the Western Electric Company. It has two platinum contact points, one on the top of the post *u* and one on the bottom of the screw *t*. The circuit is opened and closed between these two platinum points. It also has two extra binding posts *e* and *f*. One of these binding posts is connected to the post *u*, which is insulated from all other metal parts of the sounder, and the other is connected through the lever *l* to the screw *t*.

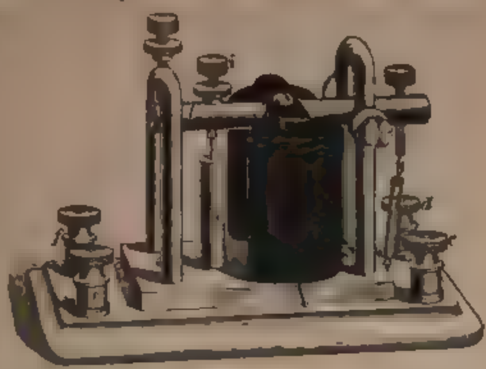


FIG. 11

36. Spring Contact Repeating Sounder. Another form of repeating sounder, which resembles the ordinary sounder made by Bunnell & Co., is, shown in Fig. 12. It has a flat spring, or tongue, *a* at one end of the lever *e* where the second circuit is opened and closed when the lever vibrates down and up.

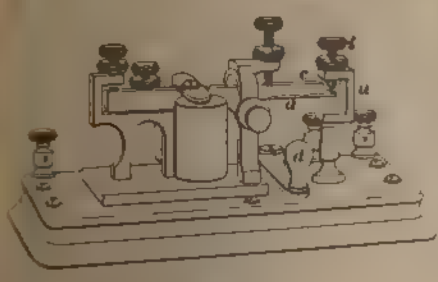


FIG. 12.

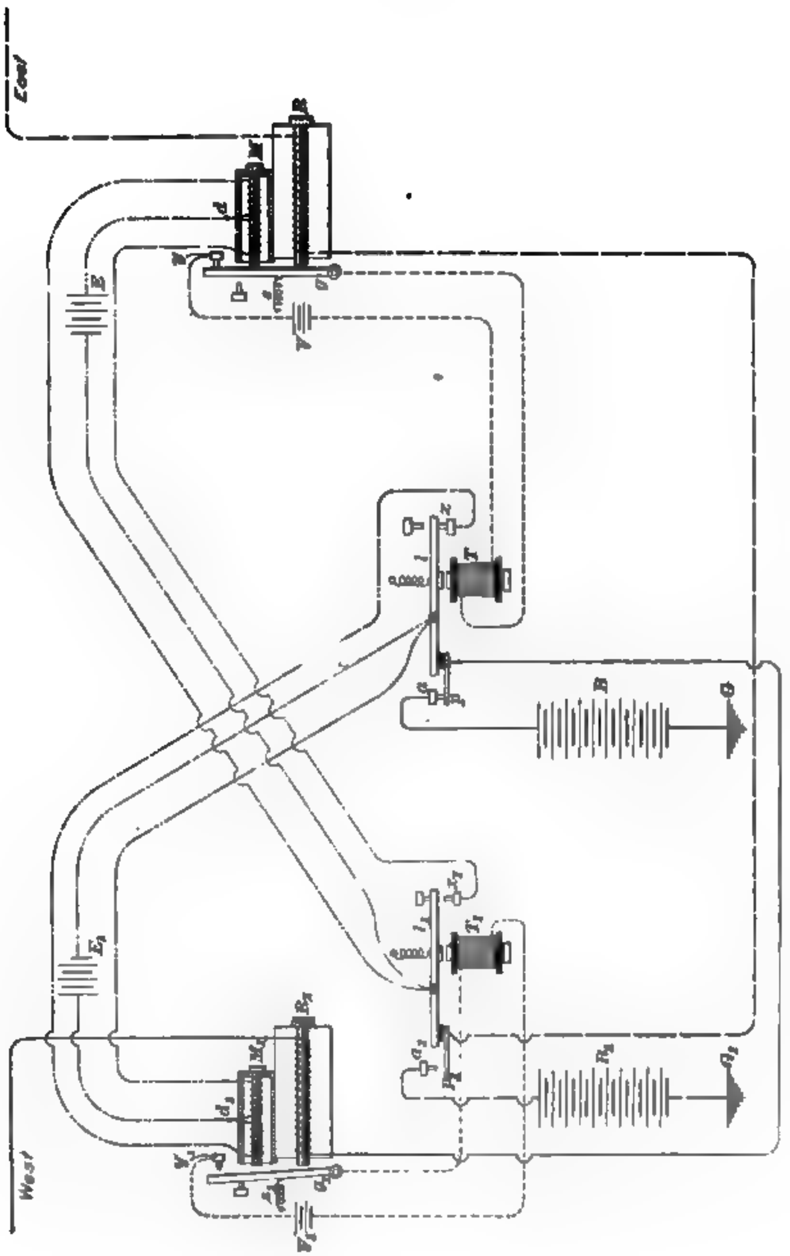


FIG. 13.

The screw i and its supporting post u are insulated from all other metal parts, except one binding post to which it is connected. The tongue a is connected through the lever to which it is fastened to a separate binding post. By means of the switch d, the circuit may be permanently opened. The Western Electric Company, also, make a repeating sounder similar to their regular sounder, but with a spring tongue.

WEINY-PHILLIPS REPEATER.

37. The **Weiny-Phillips repeater,** used by the Postal Telegraph-Cable Company, the United Press, Great Western Railway Company, and probably others, is shown in Fig. 13. T and T_1 are transmitters; B and B_1, the main-line batteries; V and V_1, the local batteries that operate the transmitters; E and E_1, extra local batteries in circuit with the extra magnets M and M_1; and R and R_1 are the main-line relays.

By means of the extra magnets extra local batteries, the continuity of the line that is repeating into the other line is preserved, resembling, somewhat, in this respect, the Milliken repeater, except that the extra magnet does not have a separate armature lever of its own, but acts directly on the lever of the line relay above which it is placed. This extra magnet is made quite different in shape and construction from the ordinary electromagnets used in ordinary relays and sounders. It has but one coil, which is enclosed in a soft-iron cylinder, open at the front and closed at the rear except for a hole at the center through which the iron core may project. In the ordinary relay magnet, the path of the lines of force is through one iron core, the yoke, the other iron core, and the armature back to the first iron core, thus completing their circuit. In this magnet the path of the lines of force is through the iron core, the rear-end iron plate, the sides of the iron cylinder, and the armature back to the iron core, from which they started.

38. Differentially Wound Magnet.—The winding and construction of the extra magnet is the distinctive feature of this repeater. There are two coils of the same number of turns and resistance on the magnet. The end of one coil and the beginning of the next are joined together and connected to a binding post on the base of the instrument. In Fig. 14 is shown an iron core over which two coils are wound in this manner. If a battery is connected between the first, or inside, end of one coil, and the last, or outside, end of the second coil, as shown at (*m*), the current, since it flows through both coils in the same direction around the iron core, will magnetize it as usual in any relay. But if the battery be connected as shown at (*n*), the current

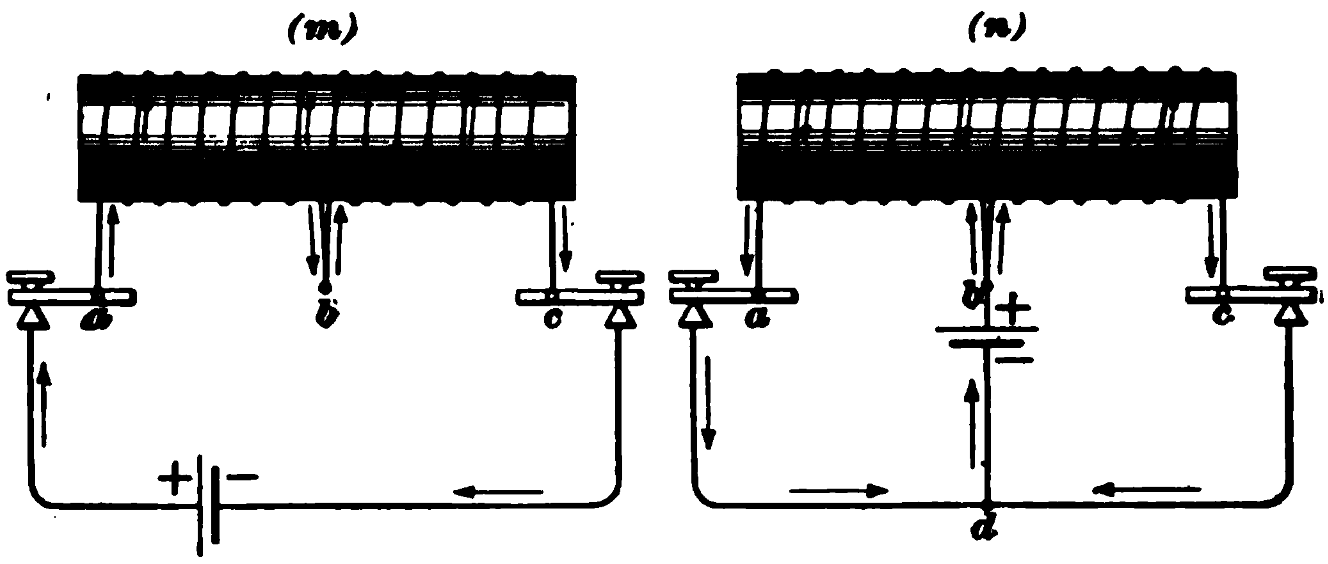


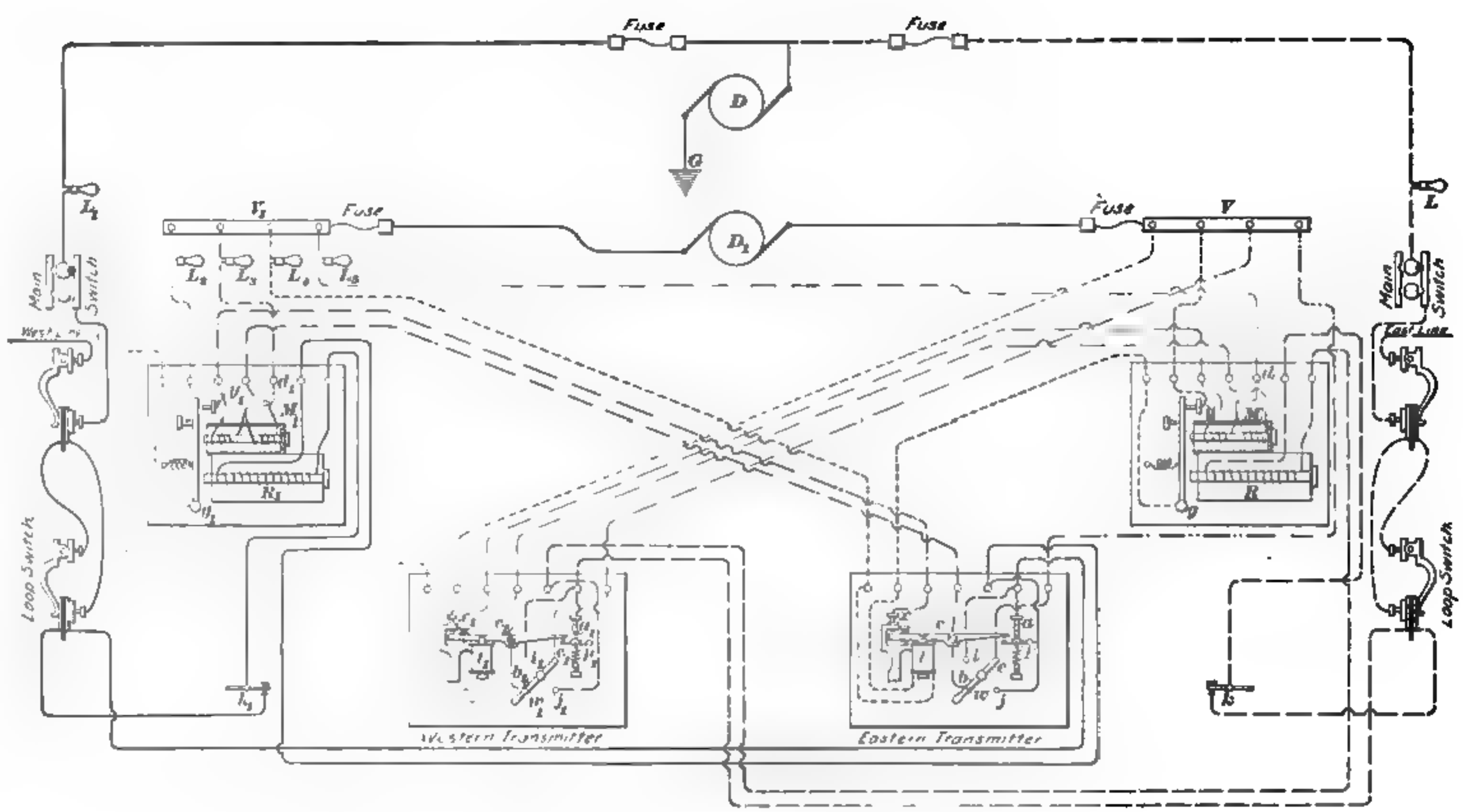
FIG. 14.

from the positive pole of the battery will divide into two parts at *b*, one flowing in the right-hand coil around the iron core in one direction, the other flowing in the left-hand coil, but in the opposite direction around the iron core. Consequently, the magnetizing forces of the two coils oppose each other, and the magnetism created in the iron core will be due to the difference in these two magnetizing forces. If both coils have exactly the same resistance, the current in each will be exactly equal; and, furthermore, if there are also exactly the same number of turns in each coil, then the ampere-turns in each coil will be equal but opposing each other; and, consequently, their resultant magnetizing force, being due to the difference of two equal opposing forces, will be zero and the core will not be magnetized at all.

However, should the key *a* in the diagram (*n*) be opened, the core will be magnetized in a certain direction because the current now circulates only through the right-hand coil, and, therefore, the magnetizing effect of this coil is not opposed, as before, by that of the left-hand coil, whose magnetizing effect is now zero. If *a* is closed and *c* opened, the core will be magnetized as strongly as before, but in an opposite direction. But as long as the armature is made of soft iron and is not polarized (that is, permanently magnetized) by the presence of a permanent magnet, the core will attract it no matter in which direction the core is magnetized. A magnet having two similar coils of the same number of turns and the same resistance, and connected as shown at (*n*), is said to be **differentially wound.** This differential method of winding a magnet has been explained here more fully, perhaps, than is necessary in connection with this repeater, but it should be thoroughly understood because many of the present duplex and quadruplex systems, which will be taken up later, would be impossible without differentially wound magnets.

39. When the transmitter T, Fig. 13, is closed, the current from the extra local battery E_1 will flow to d_{11}, where it divides *equally*, because the two circuits are equal in resistance, one half flowing through the right-hand coil of the magnet M_1 to the lever l, where it reunites with the other half that flowed through the left-hand coil on M_{11}, through x to l; from which point the whole current returns to the battery. Hence, when the transmitter is closed, as shown at T, the magnet M_1 is not magnetized and it exerts no attractive force on the armature lever g_1. When the transmitter opens, as shown at T_{11}, the left-hand coil of M is opened at x_1 and current then flows only through the right-hand coil of M. This energizes the magnet and causes it to pull the armature lever g against the contact stop y, in spite of the spring s.

40. Operation.—In the normal condition, all circuits are closed. Suppose the western key is opened, thereby



Fuse
Fuse
D
G
V_1
Fuse
D_1
Fuse
V
L_1
L
L_2
L_3
L_4
L_5
Main Switch
Main Switch
East Line
Loop Switch
Loop Switch
M_1
V_1
R_1
M
R
Western Transmitter
Eastern Transmitter
k

FIG 15.

depriving the relay R_1 of current. Since current is flowing through both coils on M_1 in opposite directions, M_1 exerts no attractive force on its armature and, therefore, the armature lever g_1 is pulled away from y_1 by the spring s_1, thus opening the local circuit, containing the battery V_1, and demagnetizing the transmitter magnet T_1. This allows the transmitter T_1 to open, at x_1, the circuit through the left-hand coil on M, thereby allowing the right-hand coil on M to energize the magnet. The magnet M will, therefore, hold the armature lever g against the stop y, when, a moment later, the eastern circuit is opened at p_1, and so cuts off all current from R. Thus the opening of the local circuit containing the transmitter magnet T is prevented, thereby *preserving the continuity of the western circuit* between p and a and, also, preventing the magnet M_1 from being energized and attracting its armature lever g_1. Therefore the eastern circuit remains open as long as there is no circuit in the western line and relay R_1. As soon as the western key is closed, the relay R_1 will be magnetized, thereby attracting the lever g_1, and closing at y_1 the local circuit through V_1-y_1-g_1-T_1. This in turn closes at p_1 the eastern circuit through R-p_1-a_1-B_1-G_1 through the ground back to the eastern office, and, also, closes at x_1 the extra local circuit containing the left-hand coil on M, thus allowing the lever g to be held in contact with y by R alone. Thus all circuits are again in their normal condition, that is, closed.

The operation of repeating from the eastern into the western circuit is the reverse. Two local circuits may be supplied from the same battery, that is, E_1 and V_1 may be replaced by one battery and E and V by another battery.

41. Arrangement of Weiny-Phillips Repeater With Dynamos.—The connections for this repeater, where dynamos are used instead of primary cells, are shown in Fig. 15. All four local circuits are supplied from one dynamo D_1 and the two main lines from another dynamo D. The little circles represent the binding posts on the base of

the instruments. L_3, L_1, L_4, and L_2 are lamps, or non-inductive resistance coils, of the proper resistance to allow the desired current to flow in their respective circuits.

On the base of each transmitter there is a switch. With these switches w and w_1 in the positions shown in this figure, that is, w connecting b with c and w_1 connecting b_1 with c_1, the apparatus is properly connected to automatically repeat in either direction, the same as shown in Fig. 13, but with dynamos substituted for primary cells. With the switches in the positions shown, the various circuits may be traced as follows: The western circuit is from the west line through the jacks at the main and loop switchboards, through k_1 and R_1 to the eastern transmitter, then through the tongue p, contact stop a, the loop and main switchboards, lamp L_1, dynamo D, and ground plate G, to the western office and west line. The eastern circuit is from the east line through the jacks at the main and loop switchboards to k-R-p_1-a_1 through the loop and main switchboards to L-D-G and back through the ground to the eastern office and east line. The circuit through the magnet t_1 of the western transmitter may be traced from D_1 through V_1-L_3-y_1-g_1-t_1-V-D_1. The circuit through t may be traced from D_1 through V_1-L_4-t-g-y-V-D_1. The extra local circuit through M_1 is from D_1-V_1-L_2-d_1, at which point the current divides into two equal parts, one part going through the right-hand coil on M_1 to c-b-c-V-D_1, the other through the left-hand coil on M_1 to x-[illegible]-b-c-V-D_1. The extra local circuit through M is from D_1 through V_1-L_2-d, at which point the current divides into two equal parts, one part going through the right-hand coil on M to c_1-b_1-c_1-V-D, the other through the left-hand coil on M to x_1-c_1-b_1-c_1-[illegible]. The repeating operation is exactly the same as that [illegible]d in connection with Fig. 13.

42. By sl[illegible]e switch w so as to disconnect c [illegible] b and to connec[illegible] j, the current is cut off from both coils of the extra [illegible] M_1, and the western main-line contact points p a [illegible]stern transmitter are short-circuited. This enab[illegible]ern transmitter to be used as a simple

sounder for the relay R_1 and, moreover, the western line still repeats into the eastern line, but the eastern cannot now repeat into the western circuit. The reverse is the case when w_1 is turned to connect i_1 with j_1 and w is in its present position connecting b with c. When both switches are [illegible]ed so as to connect i with j and i_1 with j_1, the eastern and western line circuits may be used independently of each other, the transmitters acting merely as sounders.

ATKINSON REPEATER.

43. The **Atkinson repeater,** shown in Fig. 16, requires two ordinary relays R and R_1, two repeating sounders $R\,S$ and $R\,S_1$, two transmitters T and T_1, two main line batteries B and B_1, two local batteries V and V_1, and two extra local batteries E and E_1. After the transmitters have once been adjusted and all screws firmly locked in place, they will need no further attention and the repeater can then be readily kept in proper order by any operator that is able to adjust an ordinary relay and sounder. This repeater has proved quite successful for this reason. The transmitter shown in Fig. 8 may be used in this repeater. In the *normal condition*, the two main-line, the two local, and the two extra local circuits are closed, causing the armature levers of all six magnets to be attracted, and all their local contacts to be closed *except f and f_1, which are open.*

44. Operation.—The opening of the eastern key will cause R to release its armature and to open at m the local circuit containing V and T, because [illegible] already *open* and remains so as long as T_1 remains close[illegible] [illegible]ll be shown that T_1 will not be affected at all by t[illegible]ng or closing of [illegible] eastern key and remains closed [illegible] as the western key is closed. The opening of the loca[illegible] containing T will cause this transmitter to release its [illegible] and to open the extra local circuit at d and to open [illegible] later the western circuit at a. The opening at [illegible] hol[illegible] extra local

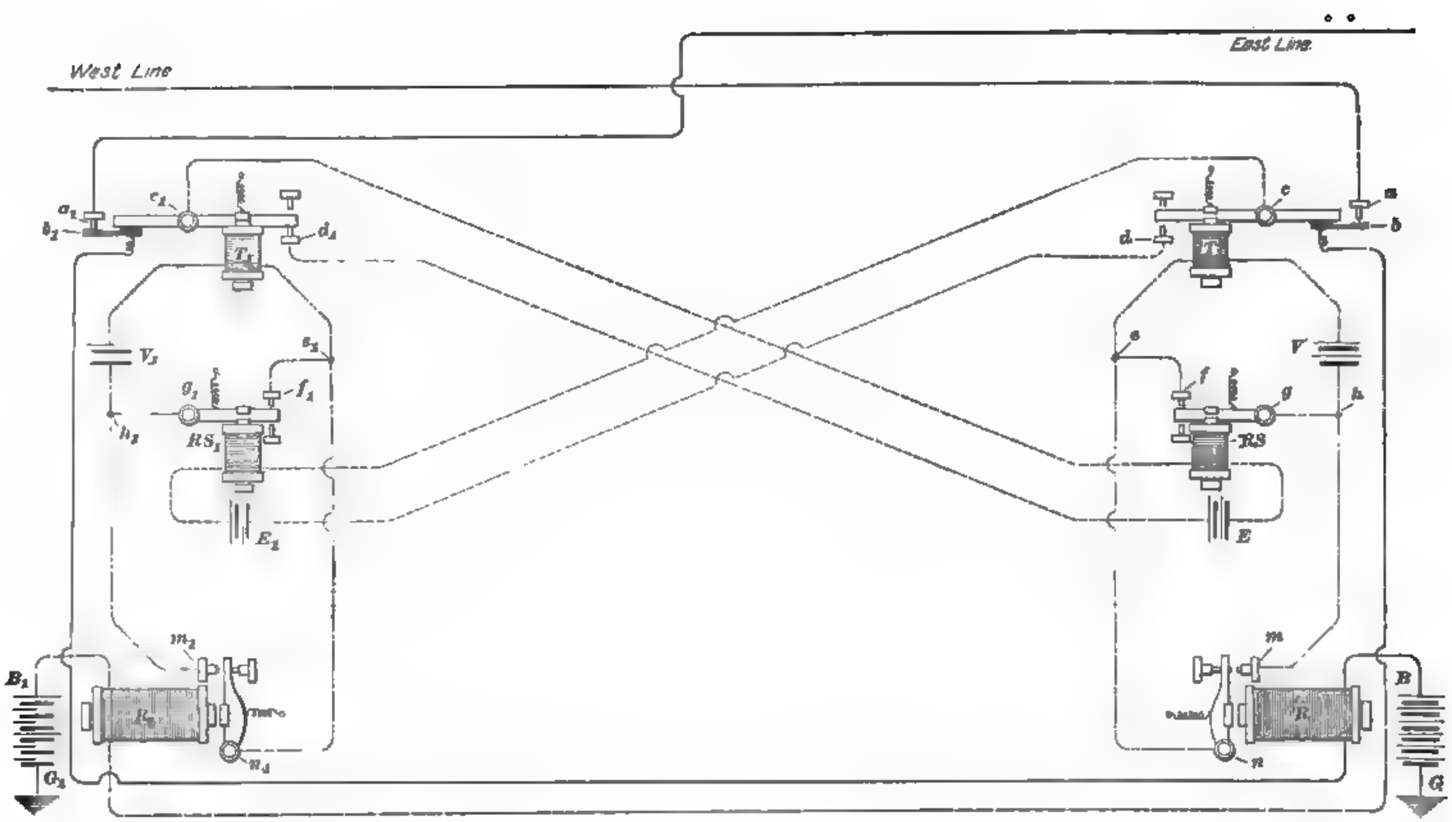

West Line
East Line
a_1
b_1
c_1
d_1
T_1
V_1
e_1
f_1
g_1
h_1
RS_1
E_1
m_1
n_1
B_1
G_1
a
b
c
d
T
V
e
f
g
h
RS
E
m
n
R
B
G

FIG. 18

circuit containing $R S_1$ and E_1 will close at f_1 the shunt circuit h_1-g_1-f_1-e_1 around the armature m_1-n_1 of the relay R_1 slightly before, or at the same instant that the armature of R_1 opens at m_1, on account of R_1 being demagnetized when the west line is opened at *a*. Thus the western circuit is opened at *a* and the transmitter T_1 is kept closed in spite of the fact that R_1 releases its armature. Furthermore, $R S$ is kept closed at d_1, thereby preventing the closing at *f* of the local circuit containing *V* and *T*, which, should it happen, would interfere with the signal. When the eastern key is closed again, *R* will close its local circuit at *m*, causing the transmitter *T* to close the western circuit at *a*, and a moment later, to close at *d* the extra local circuit containing E_1 and $R S_1$. The closing of these two circuits first causes R_1 to close its local circuit at m_1, and then $R S_1$ to open at f_1, thus restoring all the circuits to their normal condition without opening the sending line (in this case the east line) at the repeating station. Therefore, the eastern circuit is not opened at any time at the repeater station while the eastern is repeating into the western circuit. Evidently, the operation described will be reversed when repeating from the western into the eastern circuit.

HORTON REPEATER.

45. The **Horton repeater,** which was introduced in 1896, is said to have been used by the Lehigh Valley Railroad, Philadelphia and Reading Railroad, the National Transit Company, on some of the lines of the Long Distance Telephone Company, North American Telegraph Company, and the Pennsylvania Railroad lines west of Pittsburg.

46. The distinguishing feature of the Horton repeater is the method adopted for preserving the continuity of the sending circuit while repeating into the opposite line. This is accomplished by using the force of gravity, dispensing with extra armatures or springs, the holding force being

obtained by the withdrawal instead of the application of a local current. In Fig. 17, illustrating this repeater, T and T_1 are ordinary repeating transmitters and R and R_1 are main-line relays. The latter have inclined bases and local retracting magnets M and M_1 that are placed directly behind the relay armatures. The retracting magnet acts, when energized, on the armature as a retractile force (in place of the usual spring) to draw it backwards and away from its local contact when the main-line current through the front or relay coils is interrupted. On account of the inclined base,

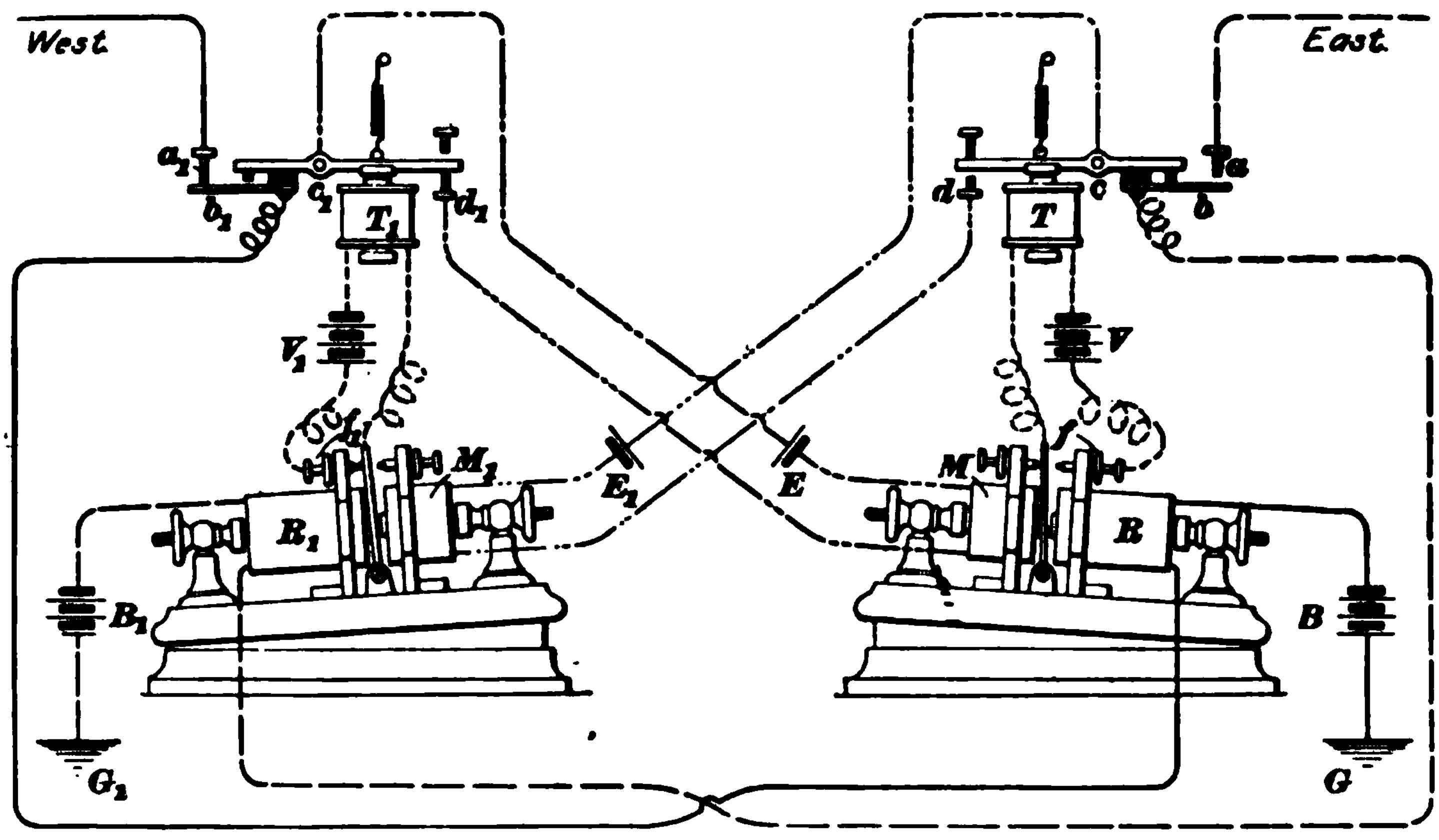


FIG. 17.

the armature will retain its forward position by gravity, and so keep the local circuit through the transmitter closed whenever there is no current in the retracting magnets, regardless of the presence or absence of a current through the relay coils in front. When both the relay and retracting magnets are energized, the pull of the relay on the armature, aided by gravity, is sufficient to keep the armature of the relay R against the front contact f, and thus keep the transmitter T closed. Consequently, the transmitter *T can only be opened when there is current in the retracting magnet M and none in the relay magnet R.*

The retracting magnet may be moved toward or away from the armature as desired, in order to increase or

decrease its attractive force on the armature, in the same manner as an ordinary relay is adjusted. This is the only part of the repeater requiring adjustment after it has once been properly set up, and for this reason it is said to give better results than some other repeaters in the hands of ordinary operators.

47. Operation.—In their normal condition, all circuits are closed. Opening the western key interrupts the current through the relay R, the armature of which is thereby drawn away from its local contact f by the attraction of the retracting magnet M, which remains closed, as will be shown presently, thus permitting the transmitter T to open first at d the local circuit of the retracting magnet M, and then at a the eastern circuit. The opening of the local circuit at d demagnetizes the retracting magnet M_1. This prevents any movement of the armature of the relay R_1, which continues to be held against its front contact stop f_1 by its own weight, when, an instant later, the east main-line circuit passing through the relay R_1 is opened at a. Thus the local circuit containing the magnet of the transmitter T_1 is kept closed, thereby preserving at a_1 the continuity of the western main-line circuit. Thus a closed path is preserved from the western office through a_1–b_1–R–B–G back through the ground to the western office, thereby enabling the western office to again close the relay R. When the western office does this by closing his key, R attracts its armature, closing at f the circuit containing T, which, in turn, first closes the east line at a, causing R_1 to hold on to its armature when, a moment later, the local circuit containing M_1 is closed at d. Now all circuits are again closed, which is their normal condition. Therefore, the western circuit is not opened at any time at the repeater while the western is repeating into the eastern circuit. Evidently the operation described will be reversed when repeating from the eastern into the western circuit.

48. It is claimed for the Horton repeater that it is very efficient and sensitive, permitting the closest possible

adjustment of both relay and transmitter armatures, the play of which may be so shortened up that their motion is scarcely perceptible, which, together with the instantaneous application of the holding force, increases the capacity of the repeater for rapid work. Any marked decrease in the strength of the extra local current can be quickly compensated for by giving the adjustment screw of the retracting magnet a turn so as to bring it closer to the armature. It is further claimed that one cell is sufficient for each extra local battery E and E_1, as against six in each extra local circuit of the Milliken repeater, and that the transmitter can be operated with less battery power on account of the close adjustment possible, thus saving about ten cells of local battery where this repeater is used in place of the Milliken.

Like the Milliken and other repeaters, the Horton repeater may be divided into half sets for use in connection with the duplex or quadruplex systems. This use of repeaters cannot be well explained until after the duplex and quadruplex systems have been considered.

SIDE-LINE AND MULTIPLE REPEATERS.

49. Most of the repeaters described can be readily adapted to repeat from a main line at an intermediate station into a branch or side line. Furthermore, by continuing one main line through a number of repeater sets, the one main line will repeat into all the branch lines, or one transmitter may be made to have as many extra tongues and contact points as there are lines into which it is desirable to repeat. Automatic repeater sets arranged to do this are sometimes known as **three-cornered repeaters.**

Automatic multiple repeaters have also been devised that, in one case, will repeat into eight, and, in another, into an almost unlimited number of circuits. However, standard repeaters, which the telegraph companies have on hand, can be arranged as explained above to do this, and to our knowledge no special multiple repeaters are in general use.

DOUBLE-CURRENT SYSTEM.

50. The Morse open-circuit and closed-circuit systems, explained in *Telegraphy*, Part 1, are sometimes called **single-current systems,** because the current in the line and relays, while a message is being transmitted, flows only in one direction. A dot or a dash is caused by a current flowing through the relay, while a space is caused by the absence of a current. It makes no difference in which direction the current flows through the relay, because a current in either direction will cause the relay to attract its armature.

51. The **double-current system** is one in which reverse currents, or currents in both directions through the line and relays, are employed. A current in one direction through the relays produces dots and dashes, and a current in the opposite direction is necessary in order to produce a space. The double-current system is used on all submarine cables, on polar, quadruplex, Wheatstone automatic, and printing telegraph systems, and more or less on simplex land lines throughout Europe. A **simplex circuit** is one over which only one message is sent at one time.

52. Polarized Relays. — For double-current transmission, *polarized relays* are necessary in place of the ordinary relays employed on single-current systems. A **polarized relay** is one that requires the direction of the current flowing through it to be reversed in order to move the armature from one stop to the other. A current in one direction will keep the local-sounder circuit closed at the front stop of the relay, and a current in the reverse direction is necessary before the local-sounder circuit can be opened at this point. The mere absence of a current will leave the armature of the relay against whichever stop the last current may have moved it. Dots and dashes are made by currents flowing in one definite direction and spaces by currents flowing in the opposite direction. A battery reversing key must be employed in place of the ordinary **make-and-break key.**

53. The polarized relay and the use of the double currents will be fully explained because of their importance in duplex, quadruplex, and other systems. In telegraphing by means of the Morse single-current system, the opening of the key leaves the line charged. This charge flows to earth through the path of least resistance, requiring on a long line, and especially on submarine cables, an appreciable time for the total charge to reach the earth through the ground connection at the distant end. If the key is so constructed that instead of simply opening the circuit it connects the opposite pole of the same, or a similar battery, to the line, then the charge of opposite polarity rushing from the battery into the line will neutralize more or less of the original charge remaining on the line, thus reducing the latter to a neutral, or unchanged, state much quicker than if all the original charge had to flow to earth before the line would be clear. Thus the line is ready for a new signal in a shorter time than under the single-current system and, consequently, more rapid transmitting is possible.

54. By the use of polarized relays and double currents, 190 words a minute can be transmitted by the Wheatstone automatic system between New York and Chicago, whereas, on the ordinary Morse single-current system, 80 words is about the limit on a line only 350 miles long. However, the greatest advantage of the double-current over the single-current system is probably due to the higher efficiency of the polarized relay over the ordinary relay, especially during wet weather when there is a large amount of leakage from the line.

THEORY OF THE POLARIZED RELAY.

55. Polarity of Soft-Iron Cores.—If a coil of insulated wire is wound around a soft-iron core and is connected to a battery so that the current circulates around the iron core in the direction shown by the arrows in Fig. 18 (*a*), the iron will be magnetized, having a north pole N at the

left-hand end and a south pole S at the right-hand end. If the battery be reversed, so that the current flows in the opposite direction, as shown by the arrows in Fig. 18 (*b*), then

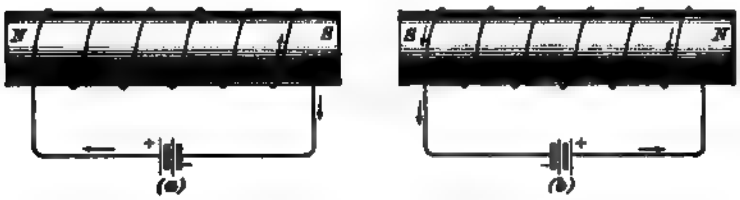


FIG. 18.

the magnetism will be reversed, having now a south pole S at the left-hand end, and a north pole N at the right-hand end.

56. A Permanently Magnetized Armature.—It is a well-known fact that similar magnetic poles repel each other and dissimilar magnetic poles attract each other. Fig. 19 represents a bar of soft iron, bent so as to bring the

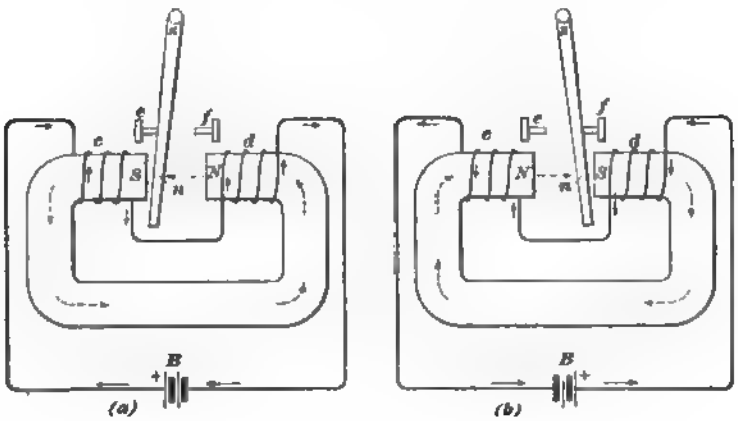


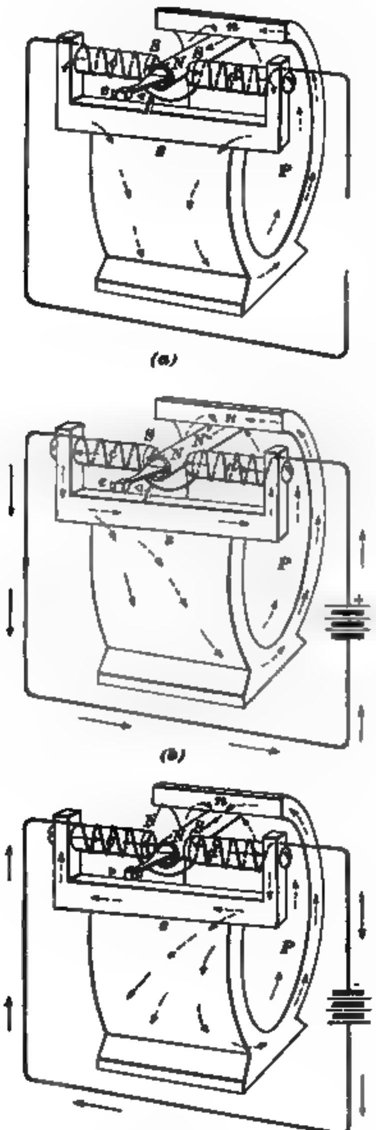
FIG. 19.

two ends opposite each other. Around each end of the iron bar is wound a coil of insulated wire, the two coils being wound in the same direction around the iron and connected in series with one another and with a battery B, as shown.

When a current from the battery circulates in the direction of the arrows shown in Fig. 19 (*a*), the current in each coil will magnetize the iron in the same direction, and thus produce magnetic lines of force in the direction of the dotted arrows, and, consequently, a north pole at *N* and a south pole at *S*. If a permanently magnetized piece of steel be suspended so that its north pole *n* is free to move between the poles of the electromagnet, the south pole *S* of the electromagnet will attract the north pole *n* of the permanent magnet, and the north pole *N* of the electromagnet will repel the north pole *n* of the permanent magnet. Consequently, the north pole *n* of the permanent magnet will move over as near to the south pole *S* as the stop *e* will permit. If the battery and, as a result, the direction of current is reversed in the coils, the lines of force in the soft iron and the polarities of the ends of the soft-iron core will be reversed, as shown in Fig. 19 (*b*). Now the north pole *n* of the permanent magnet, being attracted by the south pole *S* and repelled by the north pole *N* of the electromagnet, will move from the stop *e*, as shown at (*a*), to the stop *f*, as shown at (*b*). If the current be reversed, the permanent magnet will move back to *e*. Thus every time the direction of the current is reversed, the permanent magnet, or **armature,** as it is called, will move from one stop to the other.

57. Permanent Magnet of a Polarized Relay. In order to keep the armature permanently and strongly magnetized, and in order to otherwise increase the efficiency of the instrument, the polarized relay has a strong and rather large permanent magnet. A skeleton view of one form of a polarized relay is shown in Fig. 20. *P* is a curved piece of special magnet steel that has a very strong coercive force and which is, therefore, quite permanent and not easily weakened or demagnetized. In the rear end of this permanent magnet, the armature, or **tongue,** as it is also called, is loosely pivoted, and on the front end of the permanent magnet is placed a piece of iron of about the same

shape as that shown in Fig. 19. This rectangular piece and the tongue are made of the very best quality of magnetically soft iron. On the ends, or cores, of the soft-iron piece are wound the coils *c* and *d*. If the rear end of the permanent magnet is a north pole *n*, and the front end a south pole *s*, then, when there is no current flowing in either coil, the soft-iron parts will be magnetized on account of their contact with the permanent magnet, so as to have north and south poles where indicated by the letters *N* and *S*, respectively.



(a) (b) (c)
Fig. 20.

The dotted arrows indicate the direction of the lines of force through the various parts of the magnetic circuit. In (*a*) the lines of force are due entirely to the permanent magnet. If the tongue was exactly half way between the faces of the iron cores, it should, theoretically, remain there because each core would attract it with exactly the same force. But the least deviation in the equality of these two forces, due to the least deviation of the tongue from the exact middle position, will cause the tongue to fly against the stop *e* or *f*, toward whichever

one the pull is the greater. To get the tongue to remain in an intermediate position, where the two forces are exactly in equilibrium, would be about as difficult as it is to stand an ordinary egg on its small end. Practically, it is impossible.

58. Suppose that current flows through the coils *c* and *d*, as shown at (*b*). As in Fig. 19 (*a*), this current through the coils in the direction shown here will tend to make the right-hand end of the core, over which *c* is wound, a south pole *S*, but the permanent magnet, also, tends to make this end a south pole; hence, it becomes a stronger south pole than when there is no current flowing through *c*. This same current tends to make the left-hand end of the core, over which *d* is wound, a north pole, but the permanent magnet tends to make it a south pole; hence, it becomes either a very much weaker south pole, or a north pole *N'*, as here indicated. It is not, however, so strong a north pole as the right-hand end of the opposite core is a south pole. The result of these changes in polarities will be to create a strong attraction between *S* and *N* and a weaker repelling action between *N* and *N'*. Hence, the two cores no longer oppose each other, but both tend to move the tongue in the same direction. If the tongue was originally against the stop *f*, it will now move over against *e* and remain there even after the current is stopped. For the iron will return to its normal magnetic state when the current is stopped, as shown in Fig. 20 (*a*), in which the opposite ends of both cores become south poles again and, therefore, attract the tongue. But the attractive force of each core for the tongue varies inversely as the square of the distance between each core and the tongue; hence, the core that is the nearer to the tongue attracts it with a very much greater force than the more distant core, and the tongue is consequently held firmly against the stop *e*.

If the current be reversed in direction, the magnetic condition will be as represented in Fig. 20 (*c*) and the tongue will move from the stop *e* over against the stop *f*, because *S*

attracts and N' repels N. Thus a reversal of the current will move the tongue from one side to the other.

59. Advantages of Polarized Relays.—A polarized relay is a very efficient instrument. In the first place there is no spring to oppose the motion of the tongue or armature. Then the force that moves the tongue in one direction is exactly equal to the force that moves it in the opposite direction, because the current has the same strength in both directions. If the current in one direction weakens, it also weakens equally in the opposite direction and, hence, no adjustment is required for a variable current. Furthermore, the sending of reverse currents through the line tends to free the line more quickly of electrostatic charges and, consequently, allows more rapid sending. Polarized relays can be made exceedingly quick-acting and efficient.

60. In stormy weather a polarized relay will continue to give satisfactory service long after the ordinary, or neutral, relay becomes useless. This may be explained as follows: In *Principles of Electricity and Magnetism*, under the subject of "Lifting Magnets," it was shown that the pull between an armature and a core is proportional to the square of the number of lines of force per square inch at the pole face. Suppose, for example, that there are 200 lines of force per square inch through the armature, or tongue, of the polarized relay due to the permanent magnet alone. Half of these will go from the armature, when in its middle position, through each core, making a density, say, of 100 lines at the polar surface. Suppose, also, that the normal current produces in each core a density of 200 lines of force per square inch, then the total density in one core will be $100 + 200 = 300$, and in the other $200 - 100 = 100$, and, hence, the force of attraction toward one core may be represented by $300 \times 300 = 90{,}000$, and the repelling force of the other core may be represented by $100 \times 100 = 10{,}000$, giving a resultant pull of 100,000. If in wet weather the effective lines of force produçed by the current are reduced to 100, then the

pull toward one side will be represented by $(100 + 100)^2 = 40,000$ and the repulsion from the other side by $(100 - 100)^2 = 0$, giving a resultant force toward one side of 40,000. The resultant force has, therefore, diminished from 100,000 to 40,000.

61. In order to get the same normal pull in the neutral as in the polarized relay, let the number of lines of force set up in the neutral relay by the normal current be 223.6. Then, in fair weather, the pull between one core and the armature will be represented by $(223.6)^2$, and between the armature and both cores twice this amount, or $2(223.6)^2 = 100,000$. Thus the neutral relay is not as efficient even in fair weather, for in order to get the same pull, it must have enough ampere-turns to develop 223.6 lines per square inch, whereas the polarized relay required only enough to develop 200 lines. If we assume, as before, that in wet weather the effective number of lines of force is reduced to one-half its fair-weather value, that is, to 111.8, then the pull will be represented by $2(111.8)^2 = 25,998$.

In the polarized relay the pull is reduced from 100,000 to 40,000, whereas in the neutral relay, the pull is reduced from 100,000 to 25,998. Thus in wet weather the neutral relay exerts a pull of only a little more than one-half that exerted by the polarized relay. The less the effective current, the better does the polarized relay appear in comparison with the neutral relay, for it always has the permanent magnetism to assist the variable magnetism. Furthermore, if the force that moves the tongue in one direction decreases or increases, the force that moves it back again in the opposite direction also decreases or increases, respectively, by exactly the same amount, and, therefore, there is no retractile force to readjust. The tongue may be pulled hard one moment and lightly the next, but it will still move across the gap, and that is all that is required. Thus the detrimental effect of an extra flow of current due to leaks in wet weather is almost eliminated, because no matter how much or how little current is flowing, its direction can be

reversed, and it is on these alterations in the direction of the current that the operation of the polarized relay depends.

62. An objection to the ordinary relay is the fact that the current through the relay will vary in strength due to variation in the line resistance and in the leakage to earth in wet and dry weather; consequently, there is a variable magnetic force working against the constant pull of a spring requiring a frequent readjustment of the spring or of the cores of the magnet or of both. The polarized relay, on the other hand, has no spring for the electromagnet to overcome, and, moreover, the action of the cores on the armatures is a double one, they being attracted and repelled at the same time. No alteration in the adjustment is required (except, perhaps, to counteract earth currents, not leakage currents, which must also be done in using the ordinary relay) to meet varying strengths of line current, and for this reason the polarized relay has considerable advantage over the ordinary relay.

WESTERN UNION POLARIZED RELAY.

63. In Fig. 21 is shown a polarized relay used by the Western Union Telegraph Company. This relay was for many years their standard polarized relay. *M*, the permanent steel magnet, is semicircular in shape and 3½ inches in diameter at the widest part. The two coils *c* and *d* are wound upon soft-iron cores between which the armature, or tongue *e*, made of a soft-iron tube, moves. This armature, which is 2½ inches long, is loosely pivoted at the rear. The supports *p* and *o* for the front and rear contact screws *a* and *b*, respectively, form part of a piece that can be moved a limited distance horizontally inside the cylinder *h* by the screw *k*.

The play of the armature is usually adjusted by the screw *a*, and the armature is *centered* by means of the screw *k*. To

center the armature of a polarized relay is to place it so that it can move an equal distance on each side of a point

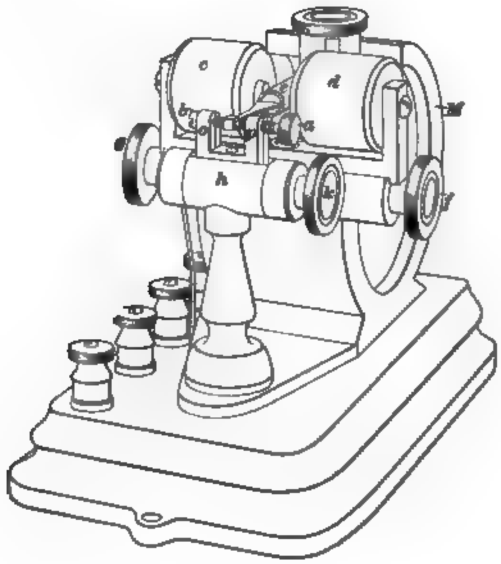


FIG. 21.

exactly midway between the faces of the two soft-iron cores. The cores, over which the coils *c* and *d* are wound, can be moved to and from the armature by the screws *f* and *g*.

NEW STANDARD WESTERN UNION POLARIZED RELAY.

64. The polarized relay shown in Fig. 21 was for many years, as has already been stated, the standard polarized relay of the Western Union Telegraph Company. Now, however, an improved polarized relay, shown in Fig. 22, has become their standard, and is displacing the other. In this connection it may be well to state that in newly designed relays, and other apparatus of the same nature, the moving parts are being made light by the liberal use of aluminum,

and quick-acting by the absence of iron yokes and a better arrangement of the iron parts.

65. In Fig. 22, illustrating this polarized relay, (x) shows the instrument complete, with part of one side cut away so that the arrangement of the parts inside can be readily seen; (y) is a plan view showing the permanent horseshoe magnet $N\ A\ S$, the two coils h and i, and the four soft-iron pole

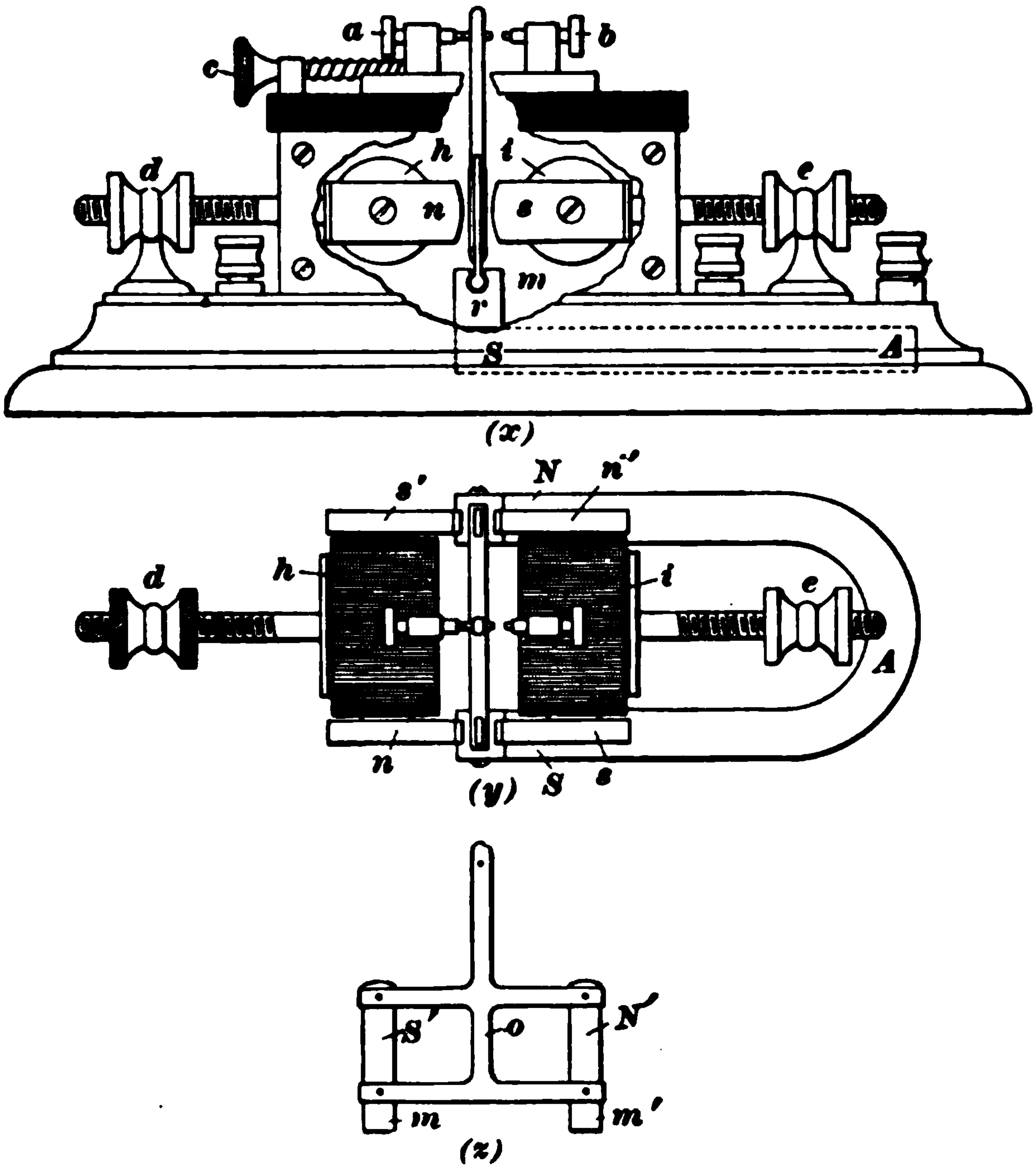


FIG. 22.

pieces s, n, s', and n' that project from the soft-iron cores to which they are fastened. The two soft-iron armatures stand in a vertical position between the pole pieces. The armature frame is shown separately at (z). It consists of two soft-iron armatures S' and N' held together, as shown, by a frame of aluminum o.

The permanent magnet $N A S$ lies flat in the base of the instrument. Each pole has a short iron extension r, in a recess in which the lower ends m and m' [shown in (z)] of the vertical iron armatures S' and N' rest loosely. The iron armatures are polarized by the permanent magnet. If the permanent magnet has a north pole at N and a south pole at S, then the armature will be polarized as indicated by the letters S' and N', assuming that the end m rests in the extension piece r fastened to the south pole S of the permanent magnet, and m_1 in the extension of the north pole N. Each iron armature extends up between two of the core pole pieces, as shown in (x). Both armatures are attracted toward the same side by the two pole pieces attached to opposite ends of the *same core* and both are repelled in the same direction by the two pole pieces attached to opposite ends of the *other core*.

When a current circulates in one direction through the coils, the core extensions will have the polarities indicated. When the current is reversed, the polarities of all four core extensions are reversed. Thus twice as many poles are utilized in this instrument as in the older type. Furthermore, the cores are not connected by any yoke, which fact makes the relay respond more quickly to a change in the current.

The cores, coils, and pole pieces may be moved toward or away from the armatures by the screws d and e. The front and back stop-screws a and b are mounted on a frame that can be moved as a whole by the screw c. As much of the relay as may be convenient is placed in a brass case with a hard-rubber top in order to protect it from dirt and injury. However, there is left just enough of an opening in the side to allow the armatures and the core extensions to be readily seen.

The coils are usually wound differentially in sections; half of each differential winding being wound on each core, and each section containing about 2,850 turns of wire having a resistance of 200 ohms, thus making 400 ohms in each differential winding.

THEORETICAL CONNECTIONS OF DOUBLE-CURRENT SYSTEMS.

66. The use of polarized relays for simplex working is illustrated in Fig. 23. Two terminal and one intermediate offices are shown. *P R* represent polarized relays, and *K*, double-current transmitting keys. The key at each station normally rests on the back stop *c*, and the switch *l* normally connects *c* with *a*. In this position all batteries are cut out of the line circuit, resembling in this respect the Morse open-circuit system. When an operator wishes to send, he moves the lever *l* so as to connect *c* with *b*, as shown at station *E*. With the key resting on the rear stop *c*, negative current flows from *E* to *W* through the line wire, causing each

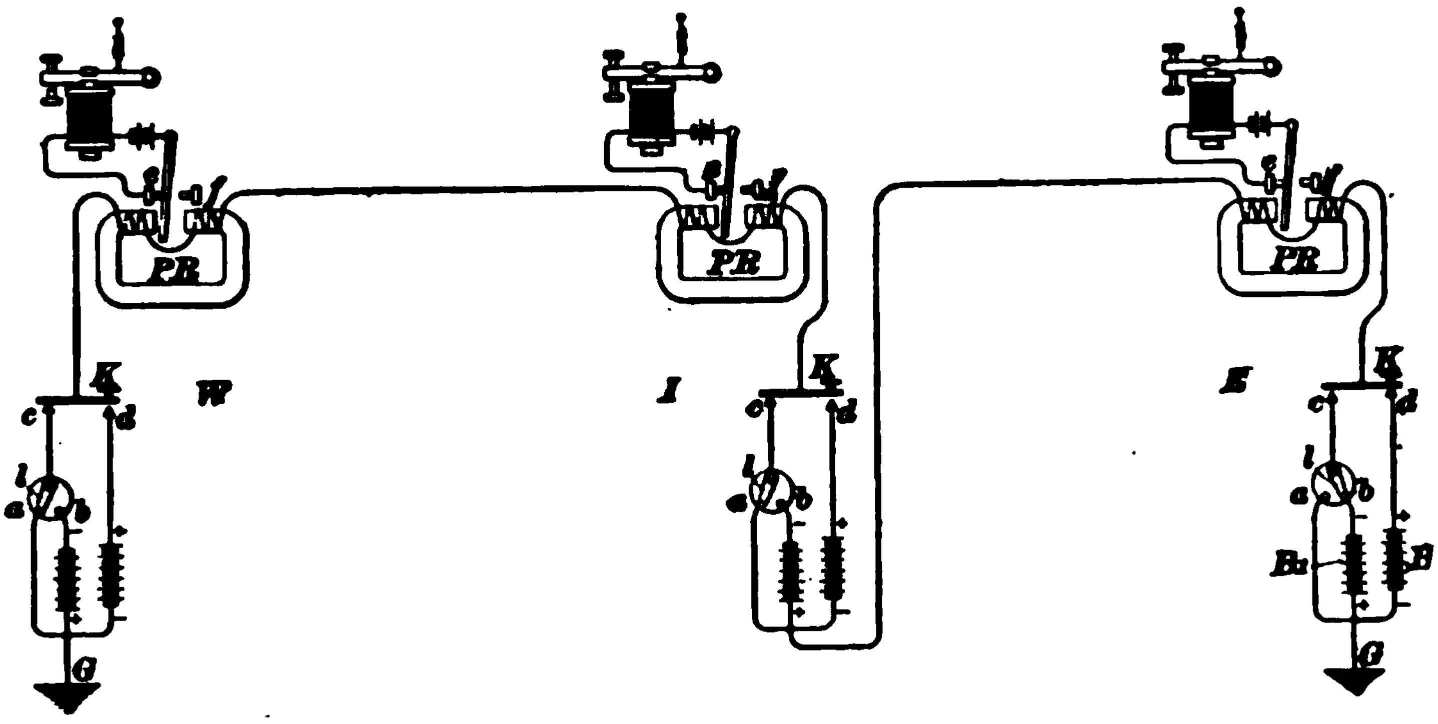


FIG. 23.

polarized relay to hold its armature against the back stop *f*, thus keeping the local-sounder circuits open. When the key is depressed, the negative charge on the line is first neutralized by a positive charge from the battery *B*; then the current rises to its maximum value and a positive current flows from *E* to *W* through the line, causing each polarized relay to move its armature against the front stop *e*. This closes the local-sounder circuits and sooner than would be the case if the single-current system were used. Current will continue to flow in the local-sounder circuits not only until the key breaks away from the front contact *d*, but until it

touches the rear contact c. Then a negative current first having neutralized or cleared out the positive charge, flows from E to W through the line and polarized relays and opens the local circuits.

67. In single-current systems, a current in one direction causes dots and dashes and no current produces the spaces. In double-current systems it is evident that starting a current in one direction starts a dot or dash, and a current in the opposite direction is required to terminate the dot or dash and start a space. The key here shown requires two batteries at each station, but there are keys, which will be shown later, that in one position connect the positive pole of a battery to the line and the negative pole to the earth, and in the other position will reverse the connections of the same battery so that the negative pole of the battery is put to the line and the positive pole to the earth. Such a key requires only one battery.

POLARIZED RELAYS AS REPRESENTED IN DIAGRAMS.

68. In Fig. 24 are shown three additional ways in which polarized relays are represented, and whenever any one of

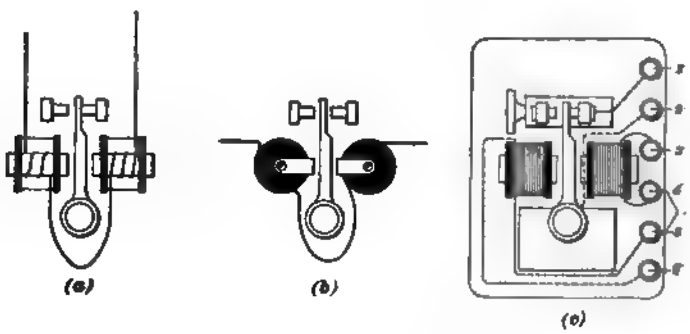


FIG. 24.

these occurs in a diagram hereafter, the student should immediately recognize it as a polarized relay. The way in

which the polarized relay was drawn in Fig. 23 and in (*a*) and (*b*) in Fig. 24 are conventional diagrams; (*c*) is a plan view of the Western Union polarized relay, showing six binding posts. Numbers *1* and *2* are the binding posts to which the local-sounder circuit is connected. Binding posts *3*, *4*, *5*, and *6* are the terminals of the four ends of the two coils. For use as a simple polar relay, *4* and *5* are connected together by a short stout wire and *3* and *6* form the two line terminals of the instrument. The use of the binding posts *4* and *5* will be apparent when the polar duplex and quadruplex systems have been described.

69. Polarized Relay Used as a Single-Current Relay.—A polarized relay may be adjusted so that it will close the local-sounder circuit when the main-line current flows through it in one direction and open the local circuit when the main-line current is interrupted. That is, it may be used in place of an ordinary relay. To use it in this way, the two stops *a* and *b* in Fig. 21 must be so adjusted that the whole play of the armature is on one side of the middle point between the two soft-iron cores. Then, when no current flows, the armature will always be drawn, due to the normal magnetic polarity of the cores produced by the permanent magnet, to the nearer core and the corresponding stop. When the key is closed, the current, in order to send a dot or dash, must circulate in such a direction around the cores as to reverse the normal polarity of the nearer core and increase the strength of the normal polarity of the other core. Then when current flows, the two cores will combine to move the armature toward the middle, but the one stop is so adjusted that the armature cannot pass or *even quite reach* this middle position, and, consequently, as soon as the current stops, the armature flies back toward the nearer pole, and against the corresponding stop. Thus the making and breaking of a current, which must flow in one particular direction with reference to the direction of the winding on the polarized relay, will move the armature and so open and close the local-sounder circuit.

MULTIPLEX TELEGRAPHY.

70. Thus far, methods for transmitting only single messages over a line have been discussed. Such systems are frequently called **simplex** to distinguish them from *multiplex* systems. **Multiplex telegraphy** is the transmission of two or more messages over the same wire at the same time. It is quite obvious that, if instruments can be arranged so that two simultaneous messages can be sent through the same wire, the work of the system is equal to that of two lines. If four messages can be sent simultaneously over the same line, the system is equivalent to a four-wire system. In these two cases a good ground return is assumed. If, then, one line can be made to do the work of four lines, the expense of erection and maintenance of three lines is avoided.

71. The transmission of two telegraphic messages simultaneously in *opposite directions* over the same wire is called the **duplex** system. This system is sometimes called **contraplex telegraphy,** to imply that the messages are being sent in contrary or opposite directions. On a duplex system there is one sending and one receiving operator at each end or office, i. e., four operators in all.

72. The transmission of two telegraphic messages simultaneously in the *same direction* over the same wire is called the **diplex** system. This term is the opposite of contraplex. On a diplex system there are two sending operators at one end and two receiving operators at the other end, or four operators in all.

73. The simultaneous transmission of four independent messages, two in one direction and two in the other, is termed the **quadruplex** system.

On a quadruplex system there are two sending and two receiving operators at each end, eight operators in all.

DUPLEX TELEGRAPHY.

74. There are three systems of duplex telegraphy: the *differential*, *polar*, and *bridge* duplex.

DIFFERENTIAL DUPLEX.

75. The **differential duplex** is also known as the **Stearns duplex.** The essential feature of this system is a differentially wound relay, the principle of which has already been explained. In Fig. 25, the differential relay R has the two outside ends of the coil extended to a distant station through two line wires $g\,h$ and $e\,f$. In one line is connected the relay R_1 and in the other a resistance r equal to the resistance of the relay R_1, both circuits then being grounded

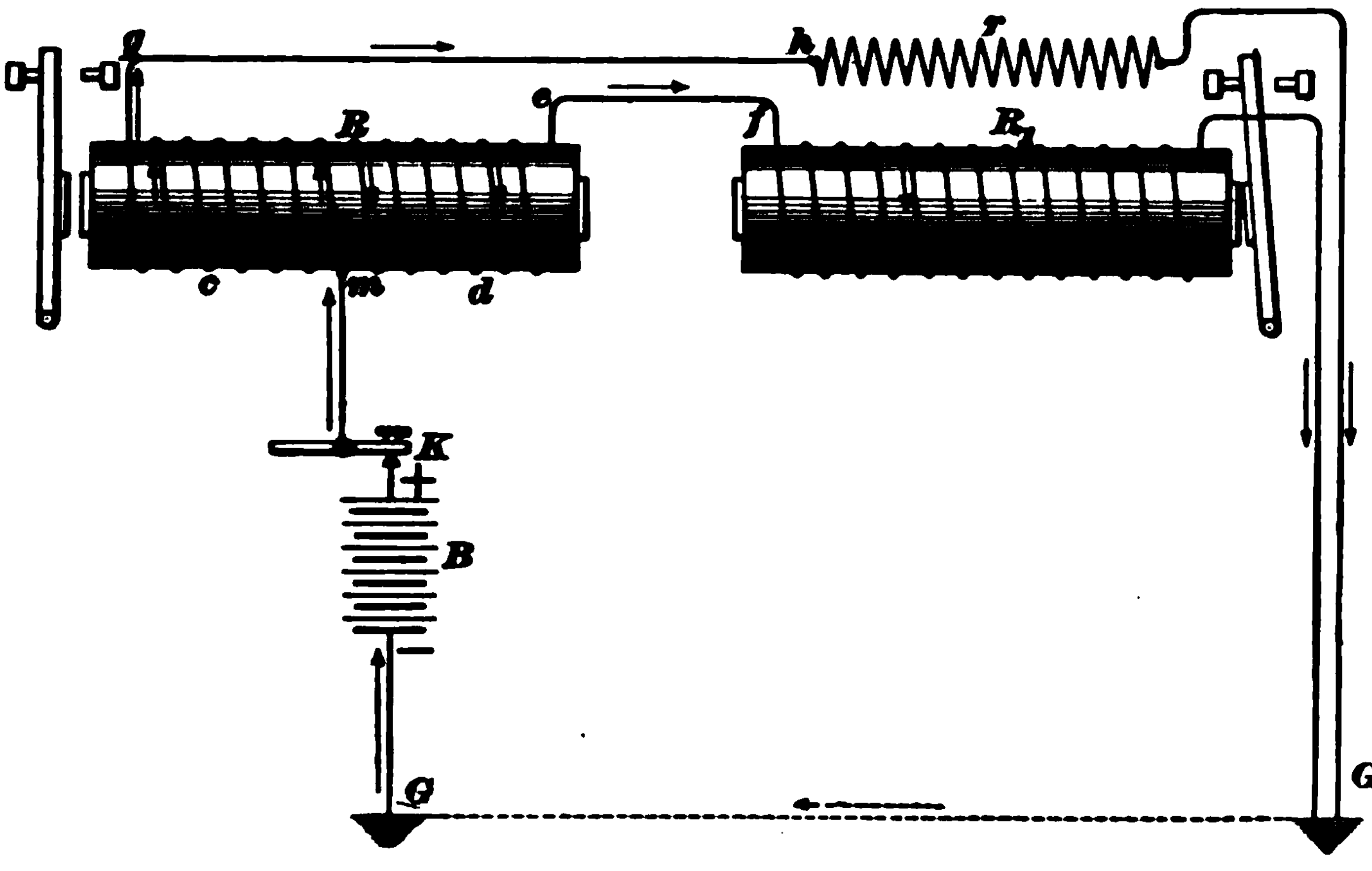


FIG. 25.

at G_1. The winding on the relay R has a connection made at its middle point, so that the two coils c and d, into which the whole winding is divided, have an equal number of turns and an equal resistance. The two line wires $e\,f$ and $g\,h$ have equal resistances and, also, equal electrostatic capacities. Consequently, the resistance and electrostatic capacity from the point m through d–c–f–R_1–G_1 is equal to that through

c–g–h–r–G_1. Therefore, when the key K is closed, the current will divide equally at m, one-half flowing to G_1 through each of the above two circuits, and the relay core R will not be magnetized because two equal currents flow around it in opposite directions. The magnetizing effect of one coil is completely neutralized by that of the other coil. Such a differentially wound non-polarized relay is commonly called a **neutral relay.** Not only will the steady or final current strength in both coils be the same, but since the capacities, as well as the resistances, in the two circuits are equal, the currents in both coils of the neutral relay will rise and fall at exactly the same rate. If the current should reach its maximum value or fall from its maximum value to zero much quicker in one coil than in the other, the armature of the relay would be momentarily affected every tir home key was closed or opened. By the arrangement shown in this figure, however, *the home relay R is not affected by the operation of the home key K.* This is one of the conditions that must be fulfilled in any successful duplex system. At the distant end, the current that flows over the line cf will flow through the relay R_1, and, consequently, that relay will respond every time the key K' at the other end is closed, provided, of course, that the current has sufficient strength.

76. Instead of extending the end of the coil c through the line gh and the resistance r to the ground G_1 at the distant end, let it be grounded at G at the home station, as shown in Fig. 26, including between g and G a resistance r equal to the resistance from c through the line cf and the coil d_1 to the ground G_1, and a condenser C having a capacity equal to that of the line cf and so arranged that it will charge and discharge at the same rate as the line. Evidently, the opening and closing of the key K will have no effect on the home relay R, but it will operate the distant relay R_1. The condenser C is a very necessary part of this equipment. For if no condenser is used, the current will rise to its maximum value in one coil of R before it does

in the other, causing a movement, or momentary *kick*, as it is called, of the armature every time the home key is opened or closed. This kick of the armature would cause *false signals* every time the home key was operated and would seriously interfere with incoming signals and render the method useless, except, perhaps, on very short lines.

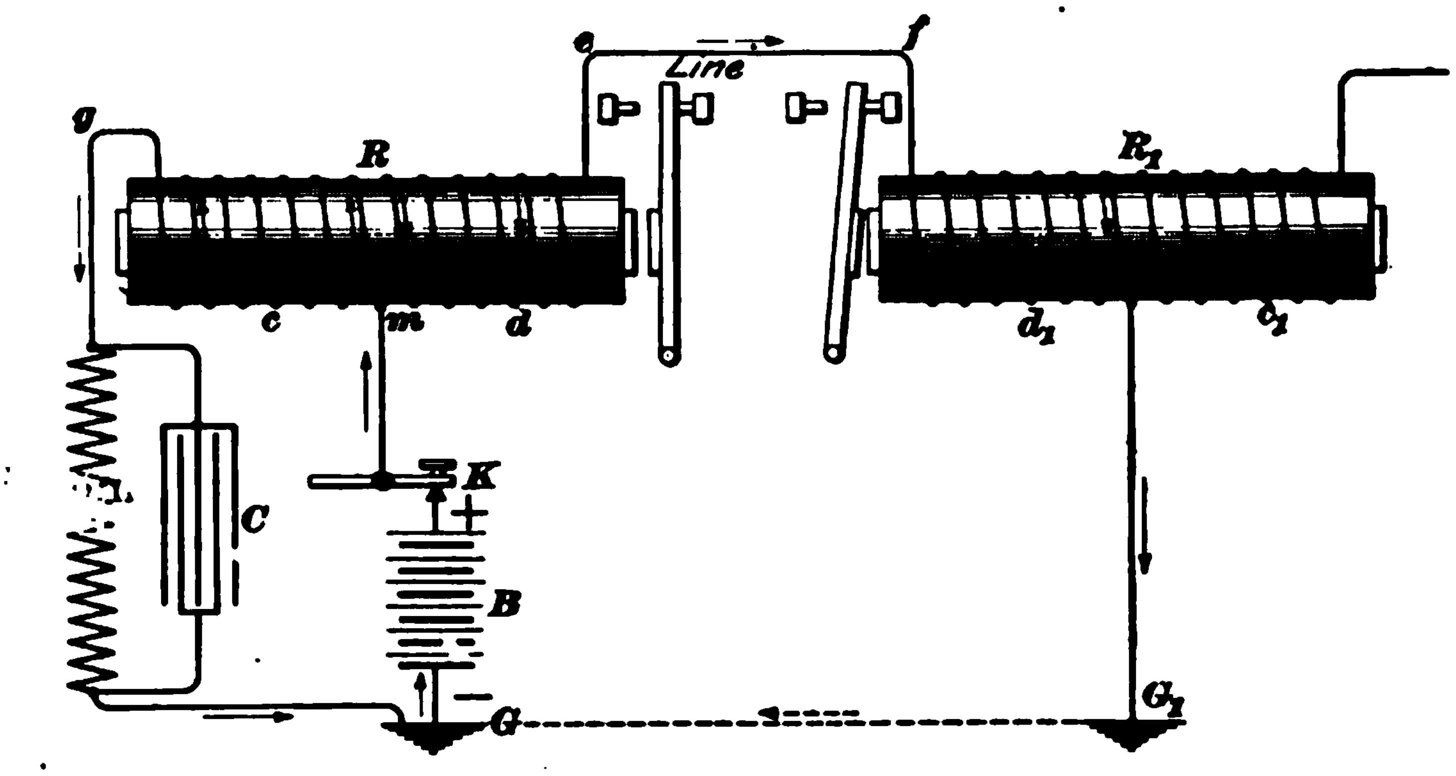


FIG. 26.

The application of the condenser to the artificial line in order to give it a capacity equivalent to that of the line, was first made by Stearns in 1872. Without this discovery of Stearns, who was a pioneer inventor in duplex telegraph work, the duplex and quadruplex systems at present in use would not be practicable.

77. In order to transmit messages in both directions simultaneously, the arrangement of apparatus at each end must be similar, as shown in Fig. 27. The keys have rear and front contacts and, normally, the levers of the keys rest on the rear contacts, which are connected to the ground. Thus the key arrangement resembles that used on the Morse open-circuit system. The resistance and capacity of the circuit from m through the coil c and $\frac{r}{C}$ to G should be equivalent to the resistance and capacity of the circuit

from m through d–e–f–d_1–n–a_1–J_1–G_1. Similarly, the resistance and capacity of the circuit from n through c_1 and $\frac{r_1}{C_1}$ to G_1 should be equivalent to that of the circuit from n

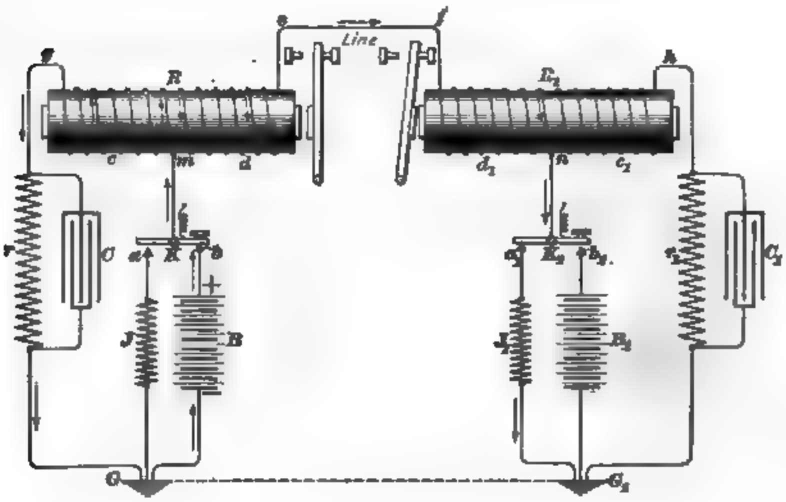


FIG. 27.

through d_1–f–e–d–m–a–J–G. The circuit from g to G, containing r and C, and the circuit from h to G_1, containing r_1 and C_1, are called the *artificial lines;* the coils c and c_1, the *artificial-line coils;* and the coils d and d_1, the *line coils* of the relays.

78. A resistance J equal to the internal resistance of the battery B must be inserted between the ground plate G and the rear contact a of the key. This will give a path of equal resistance from m to the ground G, whether the key K rests on the front or rear contact. J_1 is a similar resistance, equal to the internal resistance of B_1. If such resistances are not used, the home relay, assuming the distant key to be closed, will be more strongly magnetized when the home key is open than when closed, because the current through the line coil d of the home relay will be greater when the

home key K is open than will be the current through the artificial-line coil c when the key K is closed. The unequal magnetization of the relay will produce an inequality in the signals that it is very desirable to avoid.

79. The capacity at C and C_1 should be arranged to resemble the distributed capacity of the line wire. A simple condenser will charge and discharge more quickly than a line wire, in which the capacity is distributed throughout its length. The longer the line and the larger its capacity, the more care must be taken to make the artificial line resemble it. The way in which this is accomplished will be explained in connection with the practical arrangement of the various systems.

VARIOUS POSITIONS OF THE TWO KEYS.

80. When messages are being transmitted simultaneously in both directions, the two keys may be in such positions as to form any one of the following four combinations: both keys may rest on their rear contacts, both on the front contacts, K on the rear and K_1 on the front contact, and *vice versa.* It remains to be shown that no matter which position K occupies, the operation of K_1 will not affect its home relay R_1, but will operate the distant relay R. When this has been shown, it will be evident that, similarly, no matter which position K_1 occupies, the operation of K will not affect its home relay R, but will operate the distant relay R_1.

81. One Key Closed.—Suppose that K_1 rests on the back contact a_1 and that K is pressed against the front contact b, or **closed,** as it is called. Current then flows from the positive pole of B, charging both the line and condenser C, and, when it reaches its maximum value, flows steadily through b to m, where it divides equally, one half flowing through c and r back to the battery B, and the other half flowing through d-e-f-d_1-n-a_1-J_1-G_1 to the ground

plate G, and back to the battery B. There is also a closed circuit from n through c_1 and r_1 to G_1, but the resistance of this path is so very large, compared to that of the path through a_1 and f_1 to G_1, that it need hardly be considered. Moreover, even if there is an appreciable current in the artificial-line coil c_1, it flows in the proper direction in this case through the coil c_1 to help, and not to oppose, the magnetizing influence of the current through the line coil d_1. Thus the closing of the key K will not magnetize, temporarily or permanently, the relay R, because the currents through the two coils c and d are equal and circulate in opposite directions around the iron core of the relay, producing, therefore, no resultant magnetizing force. However, the relay R_1 is magnetized because the currents through the two coils c_1 and d_1 are not equal and opposite in direction, and, furthermore, the current in the coil d_1 is strong enough to cause the armature to be attracted. Hence, the relay R is not magnetized, but R_1 is magnetized when the battery B is connected in the circuit by closing the key K.

82. Both Keys Closed.—If, while the key K is against the front contact b, the key K_1 is closed, then the batteries B and B_1 will be in opposition in the circuit B–b–m–d–c–f–d_1–n–b_1–B_1–G_1–G–B. These two batteries contain the same number of cells and have the same electromotive force; consequently, in the circuit just traced, the current will be zero, since their electromotive forces are opposed to one another. With both keys closed, the currents in the artificial-line circuits, that is, in B–b–m–c–g–r–G–B and in B_1–b_1–n–c_1–h–r_1–G_1–B_1, are due to the electromotive force of only one battery in each circuit; hence, these currents will have their normal strength. Consequently, there is no current in the line coils d and d_1 but there is sufficient current in the artificial-line coils c and c_1 to magnetize both relays R and R_1. Thus, when both keys are closed at the same time, both relays will be closed. Although current from the home battery really closes the home relay, nevertheless it is the distant key that controls the

opening and closing of the home relay. The home key has no control over the home relay.

83. Thus it has been shown that the distant relay R_1 is energized and the home relay R unaffected when only the home key K is closed, and that both relays are energized when both keys are closed, and it is evident that the relay R is energized and R_1 unaffected when only K_1 is closed, and that neither relay is magnetized when both keys are open, because both batteries are then cut off.

84. Let us consider that whenever a current flows from the home key through the two coils on the home relay toward the line and artificial line, respectively, it is a positive current; and, conversely, that whenever the current flows from the line or artificial line through the coils of the home relay toward the key, it is a negative current. Furthermore, let the current that is flowing through one artificial-line circuit due to one battery be considered as having a strength of 1 unit. Then the four possible combinations of key and relay positions and the currents in each coil may be summarized in Table 1.

TABLE 1.

West Key K.	East Key K_1.	Western Office.				Eastern Office.			
		Current in		Difference.	Relay R.	Current in		Difference.	Relay R_1.
		Coil d.	Coil c.			Coil d_1.	Coil c_1.		
Open	Open	0	0	0	Open	0	0	0	Open
Closed	Open	+1	+1	0	Open	−1	0	1	Closed
Open	Closed	−1	0	1	Closed	+1	+1	0	Open
Closed	Closed	0	+1	1	Closed	0	+1	1	Closed

It will be noticed in the above table that whenever the difference between the currents in the two coils of one relay is not zero, the relay is closed and, furthermore, that the

distant relay is open or closed corresponding to whether the home key is open or closed.

85. Cause and Prevention of False Signals.—If, at the same moment, both keys should be in an intermediate position, touching neither the front nor the rear contact, there would be no current in any of the relay coils. Consequently, both relays would open every time this occurred, causing false signals and confusion, if means were not taken to prevent them. When gravity cells are used, false signals may be easily avoided by using a continuity-preserving transmitter that is so constructed that when it closes, contact is made with one stop before the contact with the other stop is broken. A continuity-preserving transmitter that is much used in repeaters and in duplex and quadruplex systems was described and illustrated in Fig. 5. Where dynamos that furnish current at a high potential are used, such a transmitter is not very satisfactory, on account of the injurious sparking that occurs every time the transmitter opens the short circuit it has made around the dynamo.

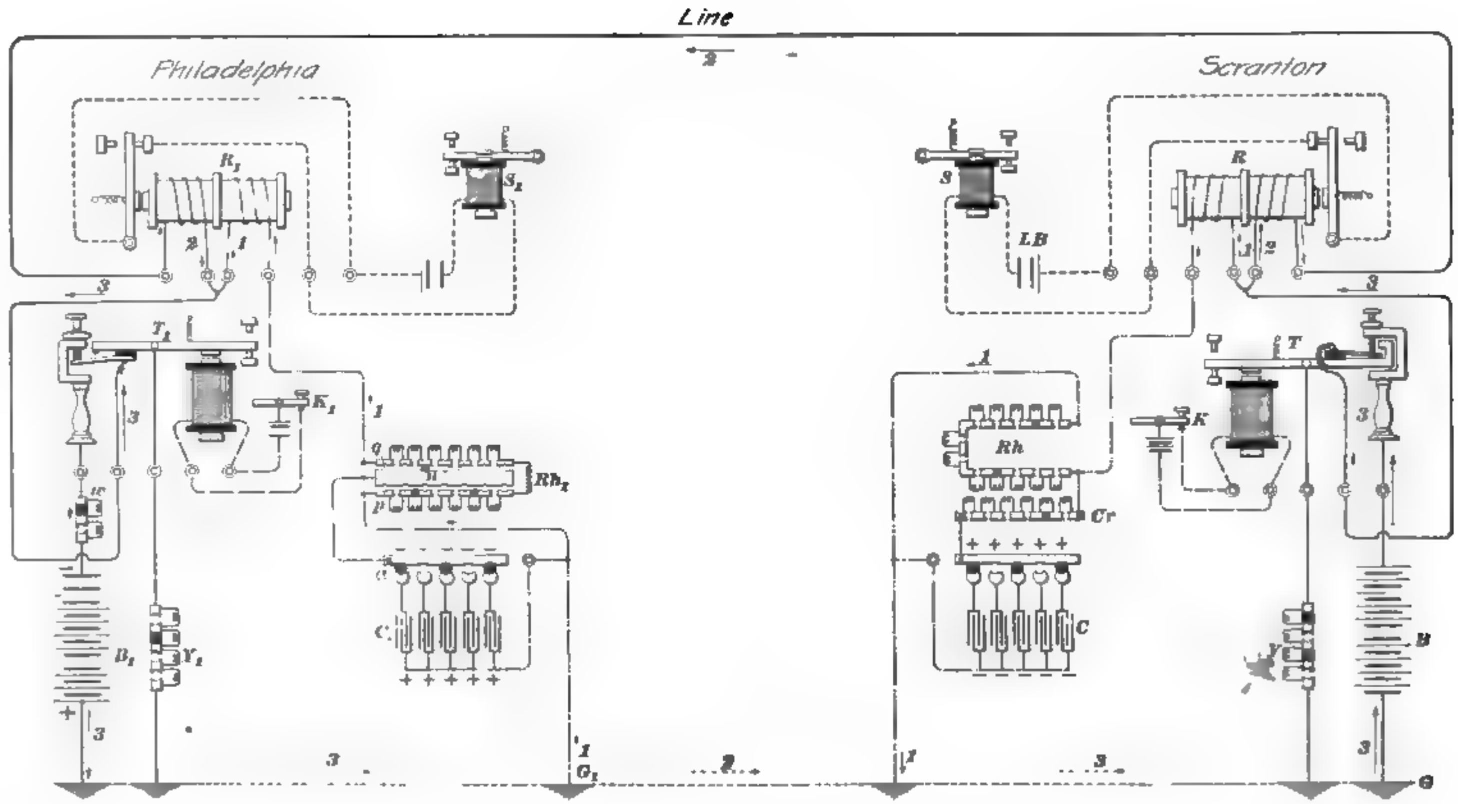
If a transmitter is used that does not perfectly preserve the continuity of the circuit, the false signals may be avoided by connecting a repeating sounder in a circuit through the *back stop* of the differential relay, and an ordinary sounder in another circuit through the *back stop* of the repeating sounder. This arrangement will give the signals properly, *provided* the interval of no current in the relay, although long enough to allow the armature to break contact with the regular front stop, is still too short to allow the armature to cross the gap and make contact with the back stop. For it is evident that the circuit of the second sounder is not closed until the armature of the repeating sounder touches its own back stop. This arrangement, which was first devised by Edison, is successfully used on the neutral-relay side of some quadruplex systems, in connection with which it will be more fully explained.

86. Method of Indicating Various Circuits.—Whenever it is not especially inconvenient or confusing to

do so, the following system of drawing in the various circuits in the diagrams for the multiplex systems will be employed: The main-line circuit will be drawn in full lines; the artificial-line circuit, in two dots and one dash; the local receiving circuit, in dots; the local sending circuit, in dashes; and the balancing ground-coil circuit in the polar, duplex, and quadruplex systems, in one dot and one dash. This plan will help the student to readily distinguish and trace out the various circuits.

87. Practical Arrangement.—The practical arrangement of the Stearns, or differential, duplex is shown in Fig. 28. The arrangement at the two ends was made slightly different in order to show both in one figure. R and R_1 are the differential relays; S and S_1, the local sounders; T and T_1, continuity-preserving transmitters; and K and K_1, ordinary telegraph keys connected in local circuits with batteries and the magnet coils of the transmitters. By using the ordinary key and a transmitter connected as shown here, operators can send better and faster than they could by using such a key as is shown in Fig. 27. In all multiplex systems where manual transmission is employed, excepting perhaps on cables, an ordinary key connected in a local circuit is used to control some form of a transmitter or pole changer. The circuit containing the transmitter, or pole-changer magnet, and the telegraph key is called the **sending circuit,** the **sending side,** or the **sending leg** when it is extended to a branch office. The resistance of the transmitter magnet is usually about the same as the sounder magnet, and the local transmitter circuits are supplied with current in the same manner as are the sounders.

88. Rh and Rh_1 are rheostats usually containing between 6,000 and 7,000 ohms, adjustable by steps of 100 ohms or less, thus permitting them to be used on lines of No. 6 B. W. G. iron wire that do not exceed about 600 miles in length. For a No. 6 B. W. G. line wire 600 miles long, as much as 9 microfarads may be required in the condenser C. At the Scranton end, an adjustable resistance Cr, called a *retarding coil*,



Line
Philadelphia
Scranton
R_1
S_1
T_1
K_1
Rh_1
B_1
Y_1
G_1
R
S
LB
T
K
Rh
Cr
C
B
G

FIG. [illegible]

is placed in series with the condenser in order that the artificial line may be made to charge and discharge as slowly as does the line. For, if the condenser discharged before the line, although the total discharge may be exactly the same, there would be a false signal due to the inequality in the rate of discharge of the two circuits. To avoid making this false signal the artificial line must be arranged and adjusted to charge and discharge at exactly the same rate as does the line, neither faster nor slower.

The condenser and resistances are arranged in another way at the Philadelphia end. The adjustable rheostat Rh_1 has a brass-center strip n to which one terminal of the condenser is joined. A plug may be placed as shown at n, so as to connect one terminal of the condenser to any coil in the rheostat.

89. Adjusting Artificial Line.—When a current of electricity is flowing through a wire, the difference of potential between two points that are near together is less than that between the points that are farther apart. Hence, as the charge that a condenser receives depends on the difference of potential at its terminals, the charge that the condenser C_1 will take may be regulated by connecting the terminal a of the condenser to different coils of the rheostat Rh_1. In this figure, it is shown connected to a coil through the plug at n. The nearer this connection is made to the line, the greater will be the resistance between the terminals of the condenser; and, hence, the greater will be the charge taken by the condenser. The nearer it is made to the ground, the less will be the charge taken by the condenser. If the plug is placed in the hole q, the condenser receives the largest charge possible in this arrangement, while if the plug is placed in the hole p, the condenser will receive no charge, as both terminals of the condenser are, practically, connected together. Thus, by adjusting the number and position of the plugs along a and the position of the plug n, and, further, by adjusting the total amount of resistance in Rh_1, this artificial line may be adjusted to

charge and discharge at exactly the same rate as the line and, furthermore, to have the same total resistance and capacity.

90. Spark Coil.—The resistance Y, which corresponds to J in Fig. 27, is adjusted to equal the internal resistance of the battery B, so that the resistance from the tongue of the transmitter to the ground at the same station shall be the same in both the open and closed positions of the transmitter. This is the purpose for which the resistance Y is used, but it is usually called the **spark coil** because it also diminishes the intensity or quantity of current in the spark when the short circuit around the battery is broken at the continuity-preserving transmitter T. The resistance w is necessary when low internal-resistance batteries or dynamos are used in place of the battery B_1, in order to prevent too large a current from flowing and injuring the contact points of the transmitter or the dynamo. In case such a resistance w is used, then the resistance Y_1 must be equal to that of w plus the internal resistance of the battery B_1. In this arrangement w is sometimes called the spark coil and Y_1 the **ground coil.**

91. The diagram is drawn to show the condition of affairs when both keys K and K_1 are closed, causing both relays R and R_1 and both sounders S and S_1 to be closed. The arrows represent the direction and the figures on the arrows the relative magnitude of the currents in the various parts of the circuit.

Practically, it makes no difference which pole of the main-line batteries is connected to the home ground. The positive of one and the negative of the other main-line battery may be connected to the ground, as shown here, or the positive or negative terminals, as shown in Fig. 27, of both batteries may be joined to the ground.

92. Adjustable rheostats are made in various forms. In Fig. 29 is shown the construction and arrangement of the coils in one form of rheostat in which the adjustment

is made by means of brass plugs, or pegs. The coils are wound back upon themselves on wooden spools so they shall have no inductance. When wound in this manner, they are called **non-inductive resistance coils.** If they were wound continuously around the spool in one direction, like an ordinary relay coil, their inductance would often be a very serious and annoying factor. It will be evident that the insertion of the plug P in the hole between the brass

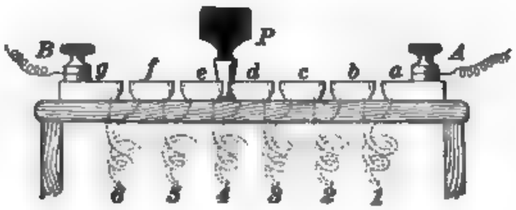


FIG. 29.

blocks e and d short-circuits the fourth coil, or "cuts it out" as it is frequently expressed. Thus, by the use of enough plugs, any number of coils may be cut out, thereby reducing the resistance as much as may be desired. The blocks are usually mounted on hard rubber and the resistance of each coil in ohms is usually stamped on the cover opposite the hole, or on the adjacent brass block or disk. This figure shows only one row of coils, but larger boxes frequently contain several rows.

93. In Fig. 30 is shown the top of a very convenient form of adjustable rheostat for use in artificial-line circuits.

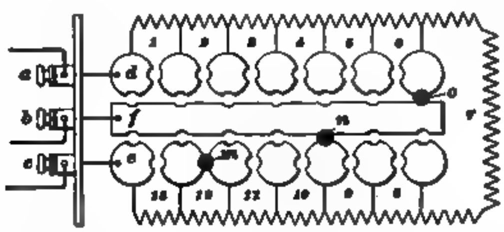


FIG. 30.

Between the two binding posts a and c, when all plugs are removed, there will be the resistance of the thirteen coils in

series; that is, the sum of all the coils whose values are stamped on the brass disks or on the ebonite cover opposite the holes. If a plug is inserted at *m*, for instance, coil *12* is cut out. If a plug is inserted at *o* and another at *n*, the intervening coils *7*, *8*, and *9* are cut out. Where this box is used on duplex and quadruplex systems, the middle brass strip *f* is connected through the middle binding post *b* to a condenser. By means of a plug, the strip *f* and, hence, one terminal of the condenser may be connected to any coil in the rheostat. In such a case, *f* would usually be connected to one disk and coil by plugging only one hole, the resistance being adjusted by plugging between disks.

94. Adjustable Condenser.—One form of adjustable condenser used in connection with various telegraph systems is shown in Fig. 31. The total capacity is divided into five sections; the capacity of the first section is 4 per cent.

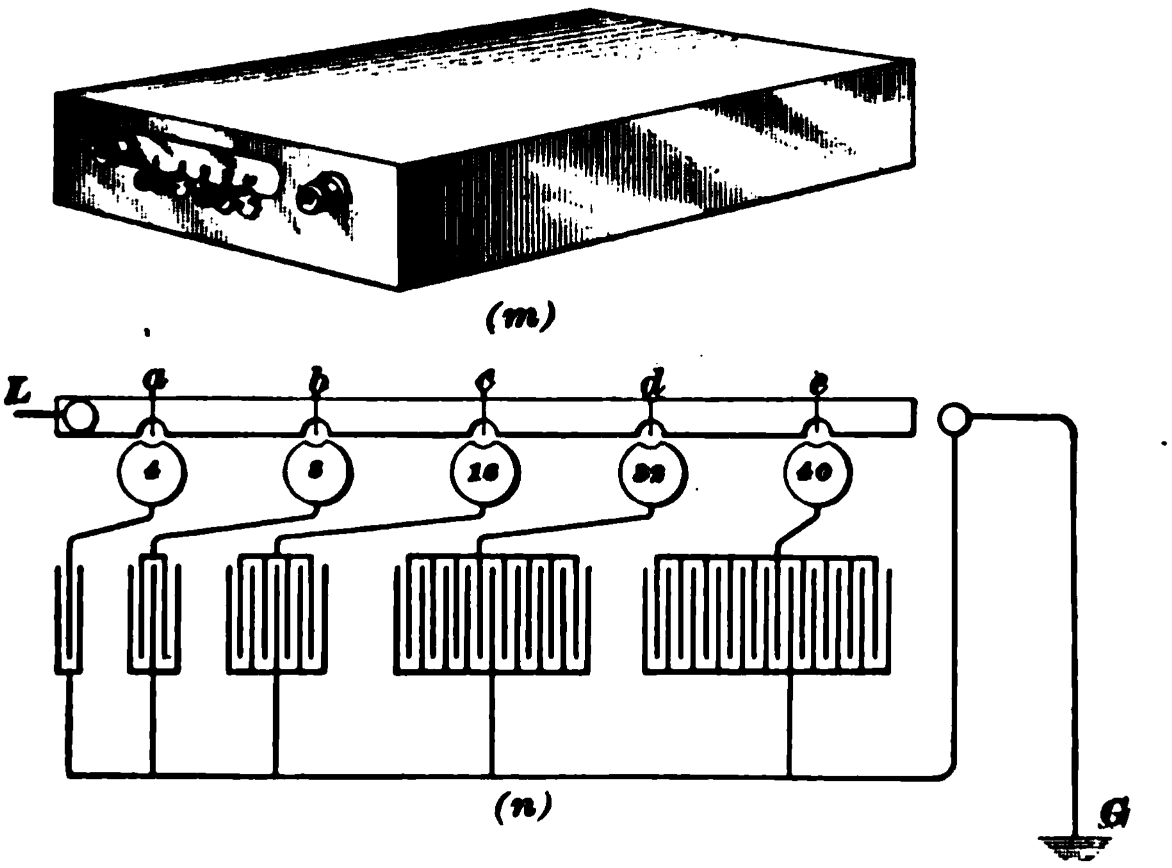


FIG. 31.

of the total capacity. The percentage capacity of each section is plainly marked on the disk to which the section is joined. If the total capacity of the condenser is 2.5 microfarads, then, by placing a plug in the hole *b*, Fig. 31 (*n*), the capacity of the condenser between *L* and the ground *G* will be 8 per cent. of 2.5; that is, .2 microfarad. By placing

plugs in the holes *a*, *c*, and *d*, the capacity will be 4 + 16 + 32 = 52 per cent. of 2.5, that is, 1.3 microfarads. The condenser can be adjusted by steps of .1 microfarad from .1 up to 2.5 microfarads. The finished appearance of the condenser is shown at (*m*).

95. Differentially Wound Neutral Relays.—Neutral and polarized relays may be differentially wound in several ways. The idea to be kept in mind in winding such relays is to so arrange the two coils that the resistance and the number of turns in each winding shall be exactly equal, and that the effect of equal currents in each coil on the movable part of the relay shall be the same in intensity. The best way would be to wind the coils with two wires,

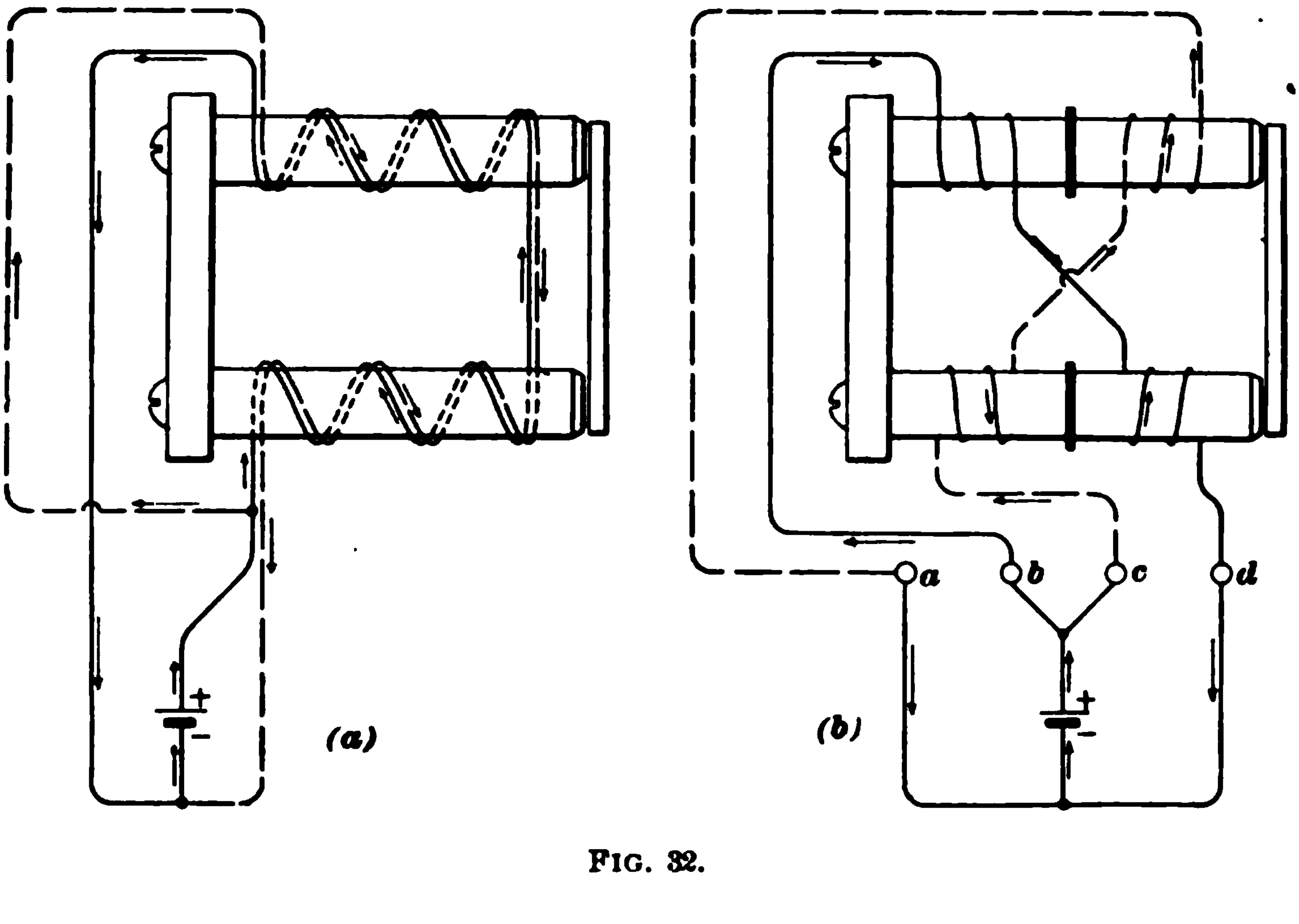


FIG. 32.

side by side, as indicated in Fig. 32 (*a*). Thus the two wires, being insulated from each other, form two coils as near alike in every way as it is possible to get them. The wires composing the two windings on each core being side by side, cause the differential action to be, largely, directly between currents in the windings, rather than between magnetisms produced in the cores by such currents. But this

is not a convenient nor a profitable way to wind them. The other extreme is to wind one coil on each core of the magnet. This is not a good way, because, although the two coils may be very much alike, they do not neutralize each other very well. A compromise that has proved satisfactory consists in winding four separate coils, two on each core, the rear coil on one core, together with the forward coil on the other core, forming one half of the differential winding, and the forward coil on the first core, together with the rear coil on the second core, forming the other half. This method of winding is shown in Fig. 32 (*b*). When the current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to current in the two windings neutralize each other. The ends of the coils are brought out to the binding posts *a*, *b*, *c*, and *d*. Evidently, an excess of current in one winding over that in the other will magnetize the relay. The Stearns differential relay, which is somewhat larger than the ordinary relay, has about 200 ohms in each winding.

BALANCING THE STEARNS, OR DIFFERENTIAL, DUPLEX.

96. Balancing a duplex or quadruplex system includes the adjustment of the various instruments and of the resistance and the capacity of the artificial line to exactly equal that of the main line, so that sending on the home key will not interfere in any way with the signals that are received at the home office from the distant office.

To balance the Stearns, or differential, duplex, ask the distant office to open his key. If Philadelphia, Fig. 28, is the distant office, the line will then be grounded through the transmitter and the rheostat Y_1. Now, turn the retractile spring of your home relay R down and adjust the magnets, as would be done with an ordinary relay, for a weak current, in order to make the relay sensitive to the slightest inequality in the division of the current through its two coils.

Make dots with your own key and vary the resistance in your rheostat *Rh* until your relay no longer responds to your own signals. Then ask the distant office to make dots and readjust your home relay to properly respond to his signals, as would be done with any ordinary relay. If a momentary kick follows each signal, it may be eliminated by varying the capacity of the condenser *C* and the resistance of the rheostat *Cr*. To eliminate the kick at an office where the arrangement is like that shown at the Philadelphia end, the capacity of the condenser is adjusted and the position of the plug *n* varied until the kicks disappear. Leakage from the line wire to the ground is equivalent to a line wire of lower resistance, and when the leakage from the line increases, the resistance in *Rh* will have to be diminished and the condenser may, also, need readjusting.

If the signals from the distant office are stronger when your key is open than when it is closed, there is not enough resistance in the rheostat *Y*, and *vice versa*. The adjustment is not complete until the incoming signals are perfect with the home key held open or closed, or when writing with it.

POLAR DUPLEX.

97. Superiority of Polar Duplex.—In good weather, the differential or single-current duplex gives satisfaction, but its efficiency falls in proportion to the increase in the current that leaks from the line wire down every pole and support to the earth. If this leakage current would disappear when the distant key is open, all would be well; but it does not, and, consequently, the effective, or surplus, current in wet weather becomes too weak to overcome the already high tension of the retractile spring attached to the armature of the relay. The polar duplex overcomes this difficulty to a great extent, and will continue to work satisfactorily long after rain storms have rendered the single-current systems useless.

98. Differential Polarized Relay.—The essential feature of the polar duplex is the differentially wound polarized relay. Fig. 33 represents a polarized, or **polar**, relay, as it is also called, with the two coils connected in three different ways with the same battery. In (x) the current circulates only in the coil c. The direction of the current and the resultant direction of the lines of force and the polarity of the poles are clearly indicated. Although there is no current in the coil d, still the lines of force created in the core by the current in the coil c will return to their original starting point through the path offering the least resistance to them, and this path of least resistance is through

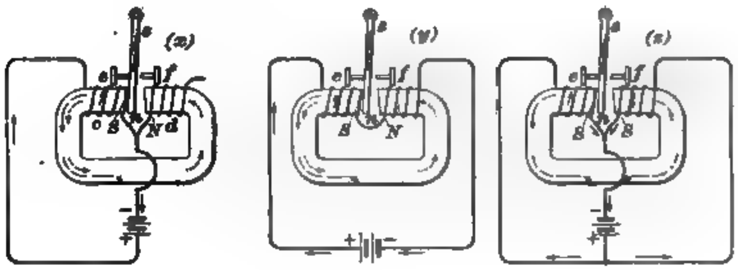


FIG. 33.

the soft iron, as shown by the dotted arrows, and not through the steel magnet, which has been omitted in this figure for the sake of simplicity. Thus the necessity of using the best quality of soft iron for this part of the relay is evident. On account of the lines of force produced by the permanent magnet, shown by means of arrows drawn with dashes, which make a north pole at n on the tongue, and those produced by the current in the coil c, shown by dotted arrows, there will be a strong south pole at S, and a weaker north pole at N. This will cause the armature to rest against the stop e. If the battery be reversed, the tongue will be drawn against the stop f.

In (y) the same battery is connected so that the current flows through both coils, but the strength of the current

will only be about one-half what it was in (x), because the two coils will have twice the resistance of one.

The currents circulate through the two coils around the iron in the same direction, tending, therefore, to help and not to oppose each other in magnetizing the soft-iron core. Therefore, the intensity and direction of the magnetism produced in (y) will be the same as that in (x) and the armature will be held against the stop e.

In (z) the two coils are connected differentially, so that the current from the battery divides into two equal portions, one portion flowing through each coil, but in opposite directions, around the iron. Consequently, the coils tend to magnetize the iron with equal forces in opposite directions, the result being that they neutralize each other and produce no magnetism; but the permanent steel magnet polarizes the soft-iron parts the same as if there was no current in either coil. Hence, both cores equally attract the armature and it remains against whichever stop it happened to be previously. If the battery, in this case, be reversed, the two coils will still oppose and neutralize each other. Consequently, with the coils connected as shown in (z), they have no influence at all on the tongue, no matter what may be the strength or the direction of the current through the two coils.

99. Method of Winding a Differential Polar Relay.—The differential polar relay is wound with two coils on each core in the manner explained, and for the same reasons that were given in the article on "Differentially Wound Neutral Relays." A diagrammatic view of a differentially wound polar relay is given in Fig. 34. The ends of the coils are brought out to the binding posts a, b, c, and d. When current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to the current in the two windings neutralize each other and an excess of current in one winding over that in the other will magnetize the relay.

Each of the four coils has about 2,400 turns of wire and a resistance of 200 ohms. Thus the line winding, or *line coil*,

as it is called, although it consists of two coils, has a resistance of 400 ohms, and the artificial-line winding, which also consists of two coils, has, likewise, a resistance

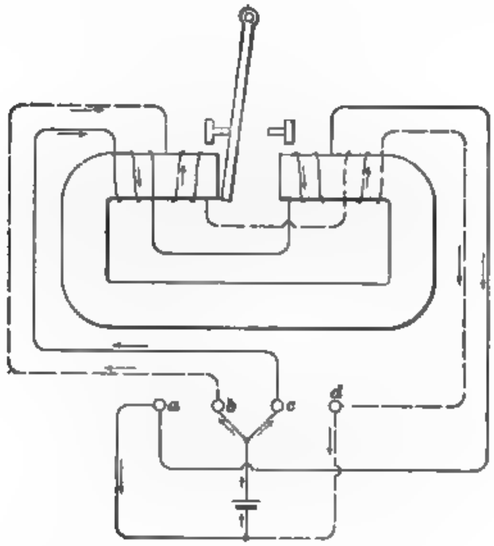


FIG. 34.

of 400 ohms. Polarized relays on duplex circuits require about 25 milliamperes, while on quadruplex circuits the minimum current required to work them varies from 15 to 18 milliamperes.

100. Theoretical Connections of Polar Duplex. The theoretical connections of the polar duplex are shown in Fig. 35. PR and PR_1 are the differentially wound polar relays, and K and K_1 are the battery reversing keys. The resistances Rh and Cr and the condenser C represent the artificial line at the left-hand station; Rh_1 and C_1 represent the artificial line at the right-hand station. All four main-line batteries, two at each end, contain the same number of cells, the negative poles of D and D_1 being connected to the rear contacts a and a_1, and the positive poles of B and B_1 to the front contacts b and b_1 of the keys K

and K_1, respectively. Since K_1 is shown closed, the circuit containing the local battery LB_1 should also have been shown closed between the armature and the stop e_1.

The levers of the keys K and K_1 normally rest on the rear contacts a and a_1, and, since the negative poles of two equal batteries, one at each end, are, in this open position of the two keys, connected to the line, there will be no current flowing in the line or in the line coils d and d_1. However, there will be current in the two artificial-line coils c and c_1, and the direction in which the current flows around the soft-iron cores will be such as to hold the armatures of both polarized relays against their back stops f and f_1. The current in either artificial-line coil due to the home battery may be represented as having a strength of 1 unit.

OPERATION.

101. Key *K* Closed.—If the western operator commences to send by pressing his key K, the positive pole of B will be connected to the relay and line, in place of the negative pole of D. This will reverse the direction of the current through the artificial-line coil c, but its strength will remain the same, namely, 1 unit. The current in the line coils d and d_1 and in the line will now have a strength of 2 units, because the resistance is the same as that of the artificial-line circuit, but the electromotive force is twice as great, because the two batteries B and D_1 are now connected in series in the line circuit, instead of opposing each other as did D and D_1 in the normal position of both keys. Hence, in the polarized relay PR, a current of 1 unit flows through the artificial-line coil c and a current of 2 units through the line coil d; but the direction of the currents in the two coils, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing through the line coil d in the direction shown by the arrow at that coil. This will produce a north pole at the left-hand end of the core on which the coil d is wound and a south pole at the

right-hand end of the core on which c is wound and, consequently, the tongue, assuming it to have a *south* pole between the two cores, will remain against the back stop f. Thus it has been shown that the closing of the key K does not affect the home relay as long as K_1 remains on the rear contact a_1.

At the east end, the current in the artificial-line coil c_1 has not changed in strength or direction. It has a strength of

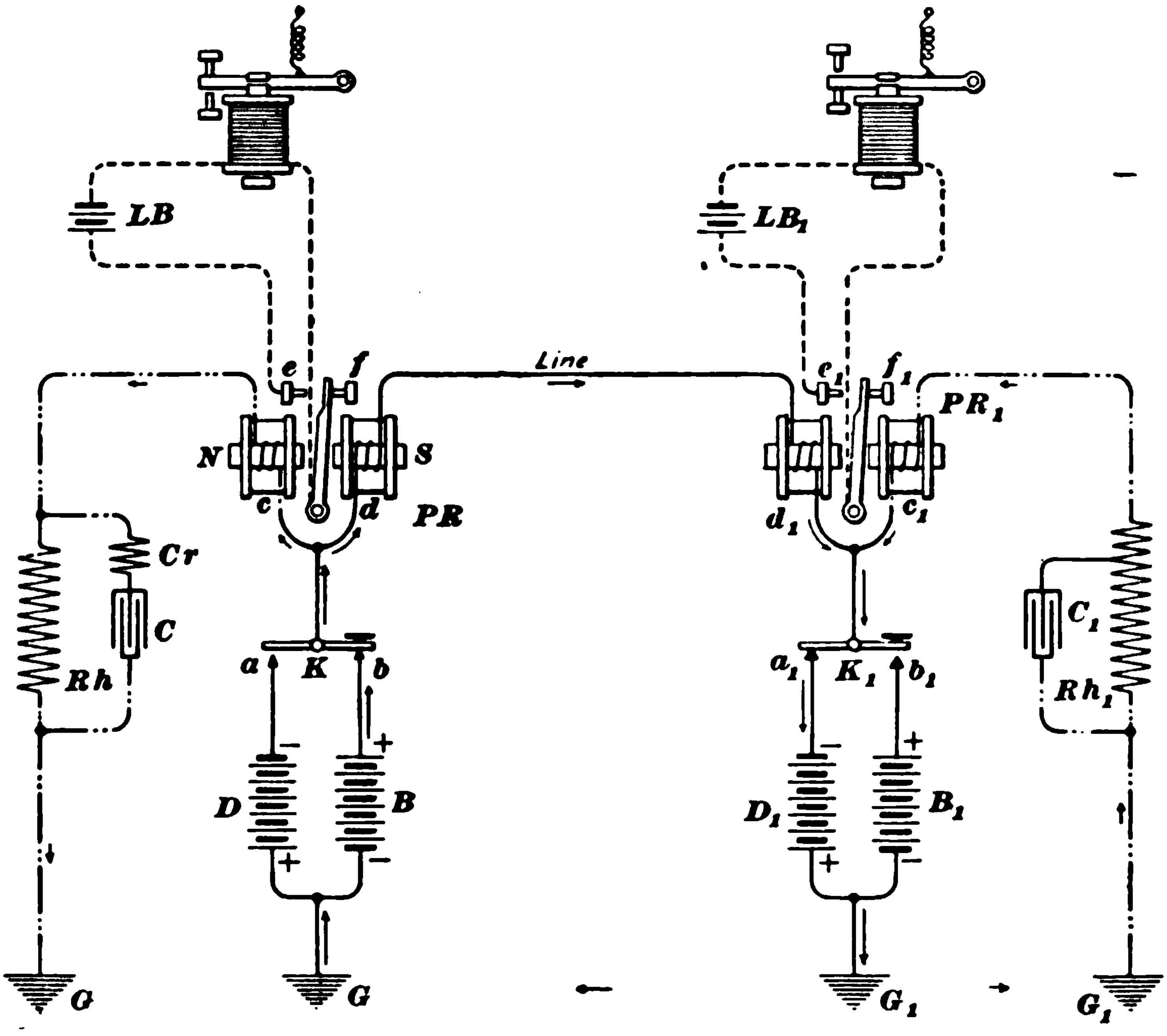


FIG. 35.

1 unit. In the line coil d_1, however, there is now a current of 2 units. The direction of the currents in the two coils, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit through the line coil d_1 in the direction shown by the arrow in that coil. This will produce a south pole at the right-hand end of the core on which the coil d_1 is wound and a north pole at the left-hand end of the core on

which the coil c_1 is wound. Consequently, the tongue, assuming it to have a *north* pole between the two cores, *will move against the front stop* e_1, although not so shown in the figure, and close the local-sounder circuit at the eastern office. Thus it has been shown that the closing of the key K when the key K_1 is open operates the polar relay PR_1 at the distant office, but does not affect the home relay. If the tongue of PR_1 is polarized the same as the tongue of PR, as is usually the case, it would only be necessary, in order to make the relay work properly, to connect the line to the coil c_1 and the artificial line to the coil d_1.

102. Both Keys Closed.—If the key K_1 is closed while the key K is also closed, the relay PR will be closed, but the relay PR_1 will not be affected and its armature will continue to remain against the front stop e_1 until the key K is released. For when both keys are closed and rest on their front contacts, the two batteries B and B_1 are connected in opposition in the line circuit. Consequently, no current flows in either of the line coils d or d_1. The current in the artificial-line coil c_1 is reversed and will produce a north pole at the left-hand end of the core on which it is wound, and a south pole at the right-hand end of the core on which the coil d_1 is wound. But this polarity is the same as before and, therefore, the tongue of the polar relay PR_1 remains against the front stop e_1, being unaffected by the change in the currents caused by closing the home key K_1, although the latter has reversed the polarity of the home batteries.

At the western office the current in the artificial-line coil c has not changed in strength or direction, but there is now no current in the line coil d. The direction of the current is such that it reverses the polarity of the cores, producing a north pole at the right-hand end of the core on which c is wound and a south pole at the left-hand end of the core on which d is wound. Consequently, the tongue of the relay PR moves against the front stop e and closes the local-sounder circuit. Thus the closing of the key K_1 when the key K

is closed, closes the polar relay PR at the distant office, but does not affect the home relay PR_1.

103. Key K_1 Closed.—If the western key K is now released, K_1 remaining closed, the two batteries D and B_1 will be in series in the line circuit, the current in the line coils of both relays will have a strength of 2 units, and the current through the artificial-line coil c will be reversed in direction, but will have the same strength as before, namely, 1 unit. The direction of the currents in the coils c and d is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing through the line coil d. This produces a south pole at the left-hand end of the core on which the coil d is wound and a north pole at the right-hand end of the core on which c is wound. Consequently, the polarity is such that the tongue of the relay PR, which has south polarity, remains against the front stop e when the key K at the western office is released. Thus, the opening of the key K has not affected the home relay PR. At the eastern station the effect of a current of 2 units flowing from the battery B_1 through the coil d_1 to the line, and a current of 1 unit from the same battery flowing through the coil c_1 to the artificial line, is equivalent to a current of 1 unit flowing from the battery B_1 through the line coil d_1. This produces a north pole at the right-hand end of the core on which d_1 is wound and a south pole at the left-hand end of the core on which c_1 is wound; thus causing the tongue of the relay, which has north polarity, to move from the front stop e_1 to the rear stop f_1. Thus, the opening of the key K while the key K_1 is closed, produces no effect upon the home relay PR, but does open the distant relay PR_1.

104. It has, therefore, been shown, no matter what may be the position of the distant key, that the operation of the home key does not affect the home relay but that it does properly operate the distant relay.

105. Let us consider, as we did in connection with the differential duplex, that whenever a current flows from the

home key through either coil on the home relay, toward the line or artificial line, respectively, it is a positive current; and, conversely, that whenever the current flows from the line or artificial line through either coil of the home relay, toward the key, it is a negative current. Furthermore, let the current that flows through one artificial-line circuit due to one battery be considered as having a strength of 1 unit. The student should remember that we assume the portion of the tongue between the cores of the relay PR to be a south pole and the portion of the tongue between the cores of the relay PR_1 to be a north pole. Then the four possible combinations of key-and-relay positions and the currents in each coil may be summarized in Table 2.

TABLE 2.

West Key K.	East Key K_1.	Western Office.				Eastern Office.			
		Current in		Difference.	Relay PR.	Current in		Difference.	Relay PR_1.
		Coil d.	Coil c.			Coil d_1.	Coil c_1.		
Open	Open	0	−1	+1	Open	0	−1	+1	Open
Closed	Open	+2	+1	+1	Open	−2	−1	−1	Closed
Open	Closed	−2	−1	−1	Closed	+2	+1	+1	Open
Closed	Closed	0	+1	−1	Closed	0	+1	−1	Closed

It will be noticed in the above table that whenever the current in the line coil minus the current in the artificial-line coil of the same relay is +1, the relay is open; and that whenever it is −1, the relay is closed. Furthermore, it will be noticed that the distant relay is open or closed according to whether the home key is open or closed.

106. Keys in Intermediate Positions.—It may be well to consider what happens to the relay during the short interval between the opening of the circuit at one contact of the key and the closing of the circuit again at the other

contact of the same key. Suppose the key K_1 rests on the rear stop a_1, and that the key K, in moving from the rear to the front contact, remains in an intermediate position, touching neither a nor b. In this position D_1 is the only battery in the circuit. It supplies a current of 1 unit to the coil c_1. The artificial line Rh at the western office, the coils c and d, the line, and the coil d_1 are in series with the battery D_1. The resistance of this circuit is double that of the line and the two line coils d and d_1, and, consequently, the current in this circuit will have a strength of $\frac{1}{2}$ unit. The current of a strength of $\frac{1}{2}$ unit in coil d_1 will oppose the current of 1 unit in c_1; but the magnetism due to a negative current of $\frac{1}{2}$ unit in coil c_1 tends to hold the tongue of the relay PR_1 against the back stop f, where it is already. Thus the relay PR_1 will not be affected until the key K touches the front stop b. A current of $\frac{1}{2}$ unit flows in the same direction through both coils c and d, so that their magnetizing forces help each other, and furthermore this current is in the same direction through c as the current of unit strength that flowed only in c when K rested on the rear contact a; hence there is produced a resultant magnetism of the same polarity and strength as when the key K rested on the rear stop a. Consequently, the home relay is not affected, and the tongue remains stationary against the rear stop f.

Suppose that both keys are in an intermediate position at the same instant. Evidently all four batteries are cut off and there is no current in any part of the system. But, now, the magnetism produced in the soft iron by the permanent steel magnet will hold the tongues on whichever side they may be, thus preventing any false signals.

POLE CHANGERS.

107. A very essential instrument in the polar duplex and quadruplex systems is the **pole changer.** This is a device for reversing the battery and, consequently, for

reversing the direction of the current in the circuit. It shifts the line from one pole of a battery to the opposite pole, and, simultaneously, does the same with the wire connected to the ground. Where dynamos are used, it shifts the line from one pole of one dynamo to a pole of opposite polarity on another dynamo. Poles of opposite polarity of the two dynamos are permanently grounded. Thus the operation of a pole changer changes the direction of the current in some part, at least, of the circuit.

A device that will reverse the direction of the current in the circuit without opening the circuit is called a **continuity-preserving,** or **circuit-preserving,** pole changer. Such a pole changer is preferable to one that opens the circuit when shifting the line from one pole of the battery to the opposite pole. While continuity-preserving pole changers are generally used where gravity cells are employed for main-line batteries, they are not practicable, and are not used where dynamos have replaced gravity batteries.

108. Continuity-Preserving Pole Changer.—The principle of the continuity-preserving pole changer is shown in Fig. 36. The battery *B* is connected to two movable spring contact strips *a* and *d*. The line wire is connected to the lever of the key *K*, and the fixed piece *b*, to the ground. In the normal, or open, position of the key, as shown in (*x*), the positive pole of the battery is connected through the strip *a* and contact *c* to the key lever and to the line; the negative pole of the battery is connected through the strip *d* and the fixed contact piece *b* to the ground *G*. In this position of the key, the direction of the current through the circuit is shown by the arrows. If the key is depressed, or closed, as shown in (*y*), the direction of the current in the *line* and in the ground circuit, as shown by the arrows, is the *reverse* of that shown in (*x*). The key, in passing from one extreme position to the other, momentarily short-circuits the battery. For the spring strips *d* and *a* may be made flexible enough and so adjusted that, as the key in (*x*) is pressed down and *c* moves up,

c first touches *d*, then *a* touches *b*, then *c* parts from *a* and finally pushes *d* away from *b*, giving the position of the contacts shown in (*y*). The reverse happens when the key moves in the opposite direction. Thus, the piece *c* momentarily short-circuits the battery and preserves an uninterrupted path from the line to the ground. This short-circuiting does not injure a gravity battery, on account of its rather high internal resistance. It may be a little hard on

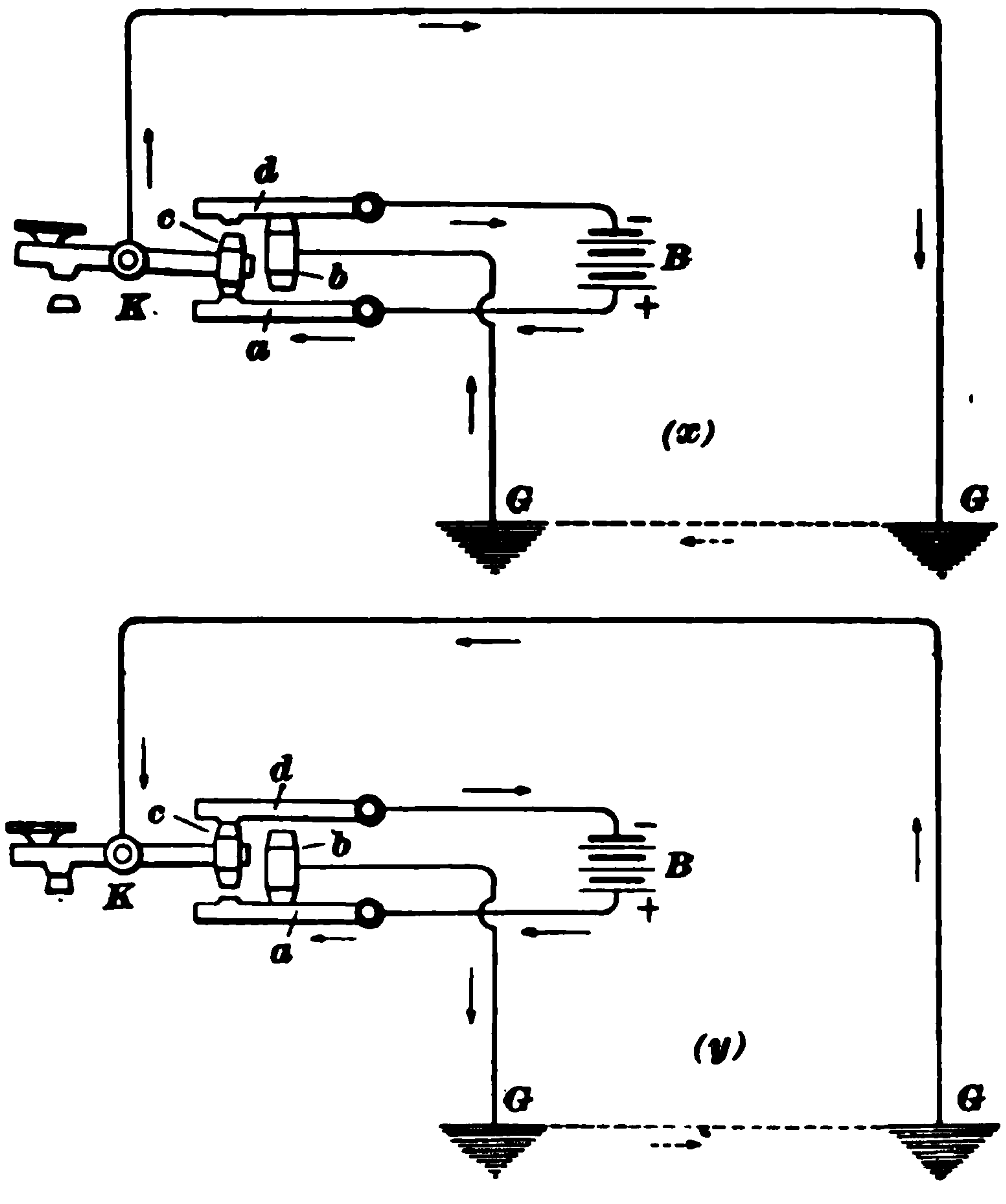


FIG. 36.

the contacts, due to the arc that is formed when the short circuit is opened, but it is not so serious as to render the method impracticable. The desirable feature of this pole changer lies in the fact that the battery is reversed with the least possible interference with the line current. In practice, the lever of the key is never manipulated directly by hand, but by means of an electromagnet, as will be shown presently.

109. B. & O. Pole Changer.—In Fig. 37 are shown the two positions of a pole changer known as the **B. & O.** (Baltimore and Ohio Railroad) **pole changer.** The contact screw *b* is placed behind the lever *f* and never touches it. When the key *k* is closed, the magnet *M* draws down the lever *PC* of the pole changer, causing the piece *e* to push *d*

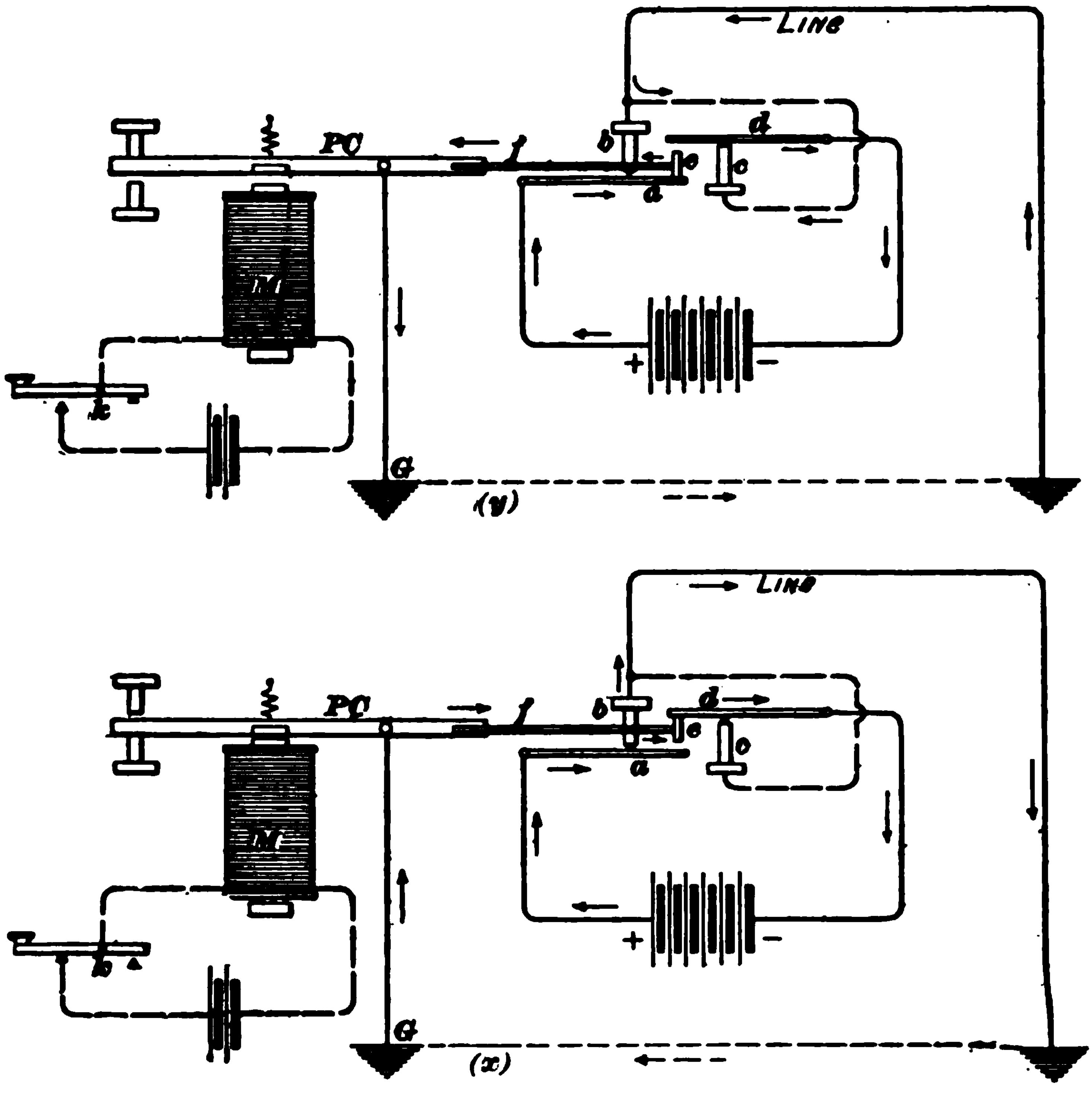


FIG. 37.

away from the contact screw *c*, and allowing *a* to rest against the contact screw *b*, thus giving the position of the contacts shown in (*x*). The springs *d* and *a* may be made long and flexible enough and so arranged that, as the lever *f* moves up, the spring *a* first touches the screw *b*, then *e* touches *d*, then *e* parts from *a*, and, finally, *e* pushes *d* away from *c*. The

arrows show the direction of the current When the key *k* is open, the position of the contacts and the direction of the current is shown in (*y*). This is a so-called continuity-preserving pole changer It momentarily short-circuits the battery because *e* touches *d* before it leaves *a*.

110. This pole changer, as made by Bunnell & Co., is shown in Fig. 38 The contact levers *a* and *d* have bearing upon them adjustable springs *m* and *n* The stop-screws *b* and *c* are also adjustable These screws and contacts are

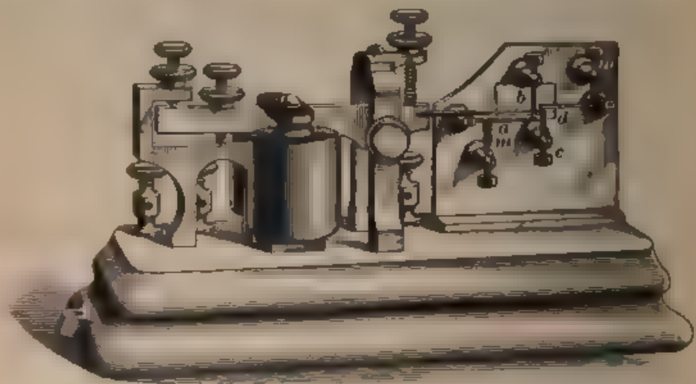


FIG 38.

not enclosed and are easy of access for the purpose of adjusting and cleaning The rest of the instrument resembles an ordinary sounder

111. Western Union Gravity-Battery Pole Changer. The so-called clock-face pole changer used by the Western Union Telegraph Company, where gravity main-line batteries are employed, is shown in Fig 39. The contacts are all enclosed in a case having a glass front, so that as much dirt and dust may be kept from them as is possible. The glass front enables one to observe the operation and condition of the contact points.

The principle of this pole changer may be understood by referring to Fig. 40 The centerpiece *c* is fastened to the

end of an armature lever and moves up and down. When down, as shown in (x), the positive pole of the battery B is connected through the strip a and the stop b to the line; the negative pole, through the strip d and the movable contact e to the ground G. The arrows show the direction of the current flowing in the various parts of the circuit. The reverse position is shown in (y). This is a continuity-preserving pole changer. It momentarily short-circuits the battery in the intermediate position and preserves a closed circuit at all times between the line and the ground G; for

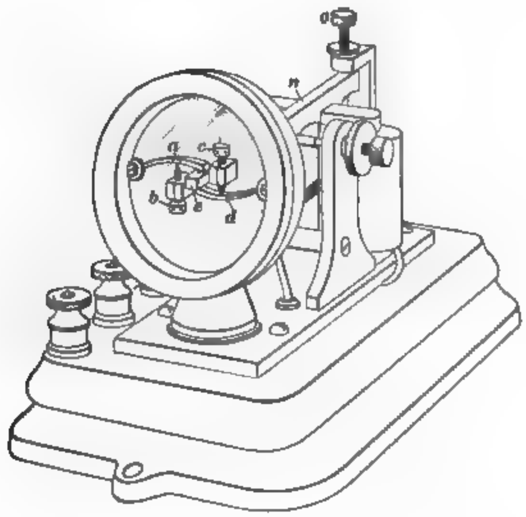


FIG. 39.

as e moves upwards, the spring d first touches the stop c, then e touches the spring a, then e pushes the spring a away from b, and, finally, e parts from the spring d. The movable piece e is in contact with both springs a and d only momentarily; in fact, all these changes follow one another very rapidly and the battery is short-circuited for only an instant When e moves downwards, the contacts are made and broken in a similar manner. The parts shown in both Figs. 39 and 40 are similarly lettered. In Fig. 39, n is the armature

lever, on the front end of which is fixed the movable contact *e*. The stops *b* and *c* are in contact with the case and connected

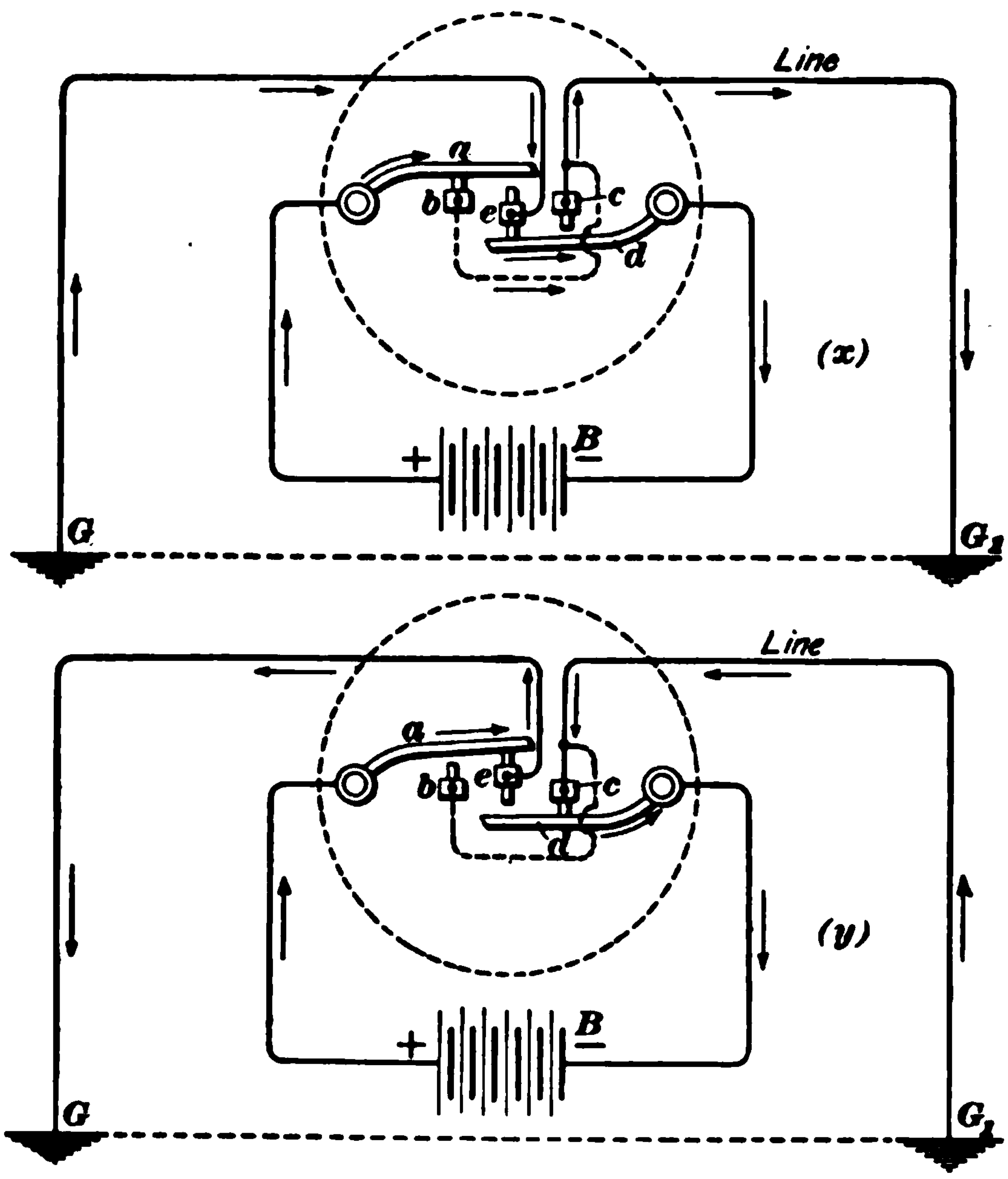


FIG. 40.

to one binding post on the base. The springs *a* and *d* and the lever *n* are all insulated and connected to separate binding posts.

112. Dynamo Pole Changers.—The continuity-preserving pole changer is not suitable for use with dynamos. Where dynamos are used, the same machine supplies all circuits requiring the same polarity and voltage. Hence, where more than one line is supplied from the same machine, it is not practicable to reverse the direction of the current in one line without also reversing it in the other lines. This can readily be done with gravity batteries, because a separate battery is used in each line circuit. Where dynamos are used for duplex and quadruplex systems to supply

positive and negative currents, a separate machine is required for each polarity, and one pole of each machine is permanently grounded.

With dynamos it has been found advisable to use a pole changer that does not short-circuit the machines, but which opens the circuit connected to one pole of one dynamo slightly before it connects the circuit with the opposite pole of the other dynamo. If a continuity-preserving pole changer were used, it would at every reversal, where 350-volt machines are employed, short-circuit 700 volts and cause the formation of bad arcs at the contact points. This would soon put the contact points in very bad condition.

113. Walking-Beam Pole Changer.—To avoid the difficulties referred to in the preceding article, the so-called **walking-beam** type of pole changer, shown in Fig. 41, is used in connection with dynamos. The line is connected to the lever, or beam, *a b* of the pole changer. The positive pole of one dynamo *C* is connected to the contact stop *e* under the *a* end of the beam, or lever; and the negative pole of the second dynamo *D* is connected to the contact stop *f* under the *b* end of the beam. The positive pole of the dynamo *D* and the negative pole of the dynamo *C* are permanently grounded at *G*. Thus, when the key *K* is closed, the positive pole of dynamo *C* is connected to the line through the lever, and when the key is open, the negative pole of *D* is connected to the line. The beam *a b* in moving from one position to the other, momentarily opens the line circuit when in its intermediate position, as is shown in this figure, but the dynamos are never short-circuited.

In circuit with each machine is a non-inductive resistance *l*, either an incandescent lamp or a non-inductively wound coil of German-silver wire. This resistance serves two purposes. It reduces sparking at the contact points, because it limits the strength of the extra current when the pole changer opens the circuit. It prevents injury to the dynamo due to overheating in case there is a short circuit. For

quadruplex circuits, the resistance of this lamp is usually about 600 ohms.

114. Theoretically, there should be no difference in the efficiency of a duplex or quadruplex circuit whether supplied from dynamos or gravity cells in strictly first-class condition.

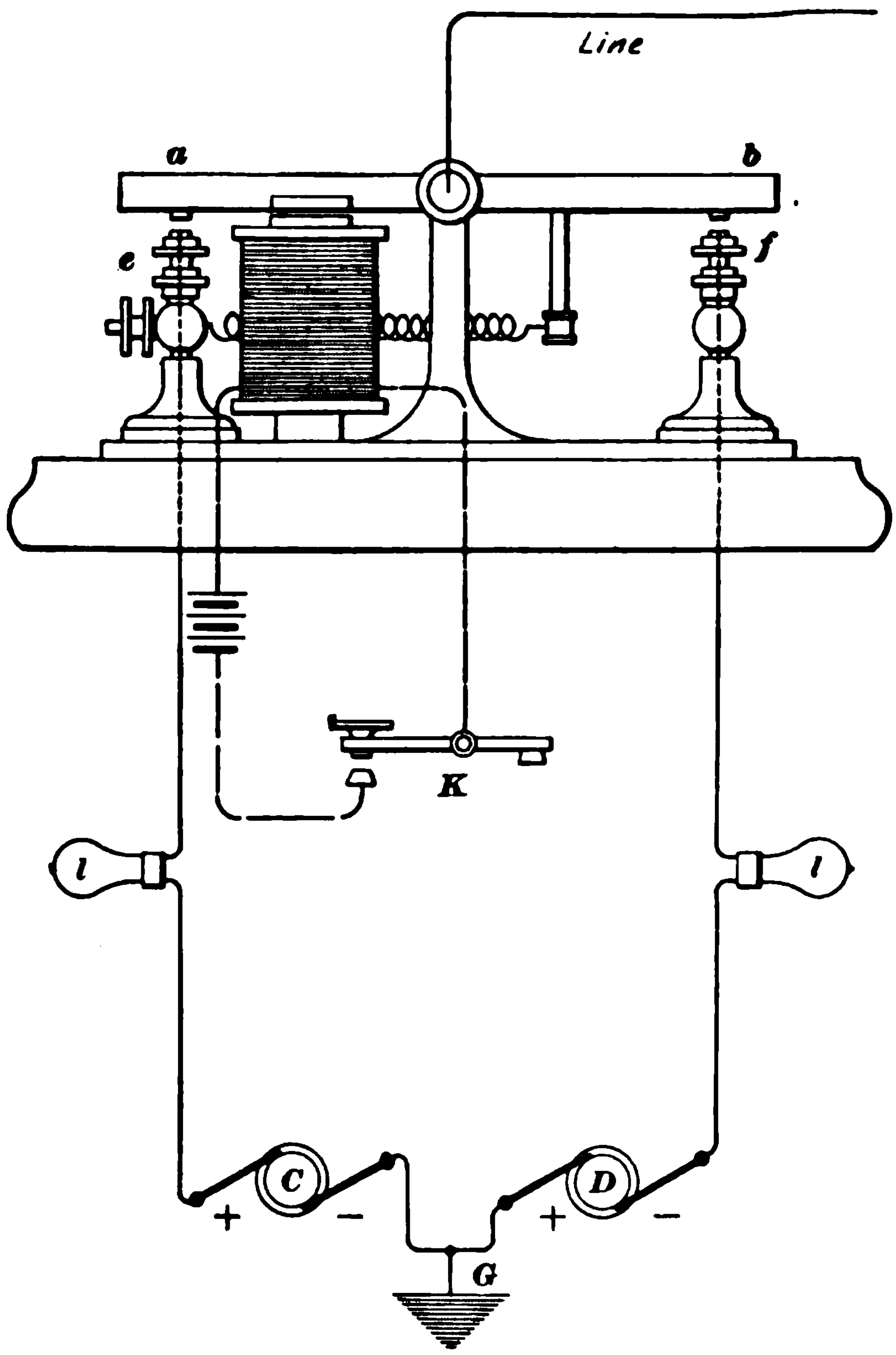


FIG. 41.

The arrangement with gravity batteries possesses the advantage of permitting the employment of the superior continuity-preserving pole changer, which is less liable to interfere with the signals on the neutral relay in the quadruplex system than is the dynamo walking-beam pole changer. On

the other hand, the dynamo is more economical and so much more reliable than a gravity battery that the dynamo arrangement gives the most satisfactory results, all things being considered.

115. Table Switch.—A form of switch that is extensively used on the tables, or desks, in connection with duplex and quadruplex systems is shown in Fig. 42. Along the top is a row of seven screws, or binding posts, to which all wires running to the switch are fastened. Along the bottom is a row of six contact buttons. The buttons *1*, *3*, *4*, and *5* are connected under the switch to the binding posts, as shown by the dotted lines. The buttons *2* and *6* are idle buttons; that is, they have no wires connected to them. The switch arm *A* may rest on button *1* or button *2*, *B* on *3* or *4*, and *C* on *5* or *6*. This makes a very convenient switch and one whose use will be apparent when diagrams for the dynamo duplex and quadruplex systems are given.

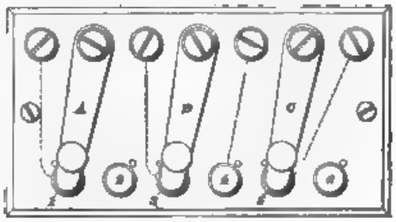


FIG. 42.

116. Polar Duplex Operated by Gravity Battery.—The practical arrangement of the polar duplex at an office where gravity cells are used is shown in Fig. 43. All the apparatus and connections have already been explained except the use of the switch *H* and the resistance *Gc*, called the *ground coil*. This resistance need not necessarily be adjustable; it may be simply a coil having a fixed resistance. The resistance from *r* through the ground coil *Gc* to G_2 should be equal to that of the circuit from *p* through the pole-changer contacts and main battery *B* to the ground *G*. When the duplex set is in operation, the switch *H* rests on *p*; but in order to balance the set, it is desirable to cut off the pole changer and the battery *B*, but to keep the resistance of the circuit the same. This is accomplished by turning the switch *H* to *r*. The resistance

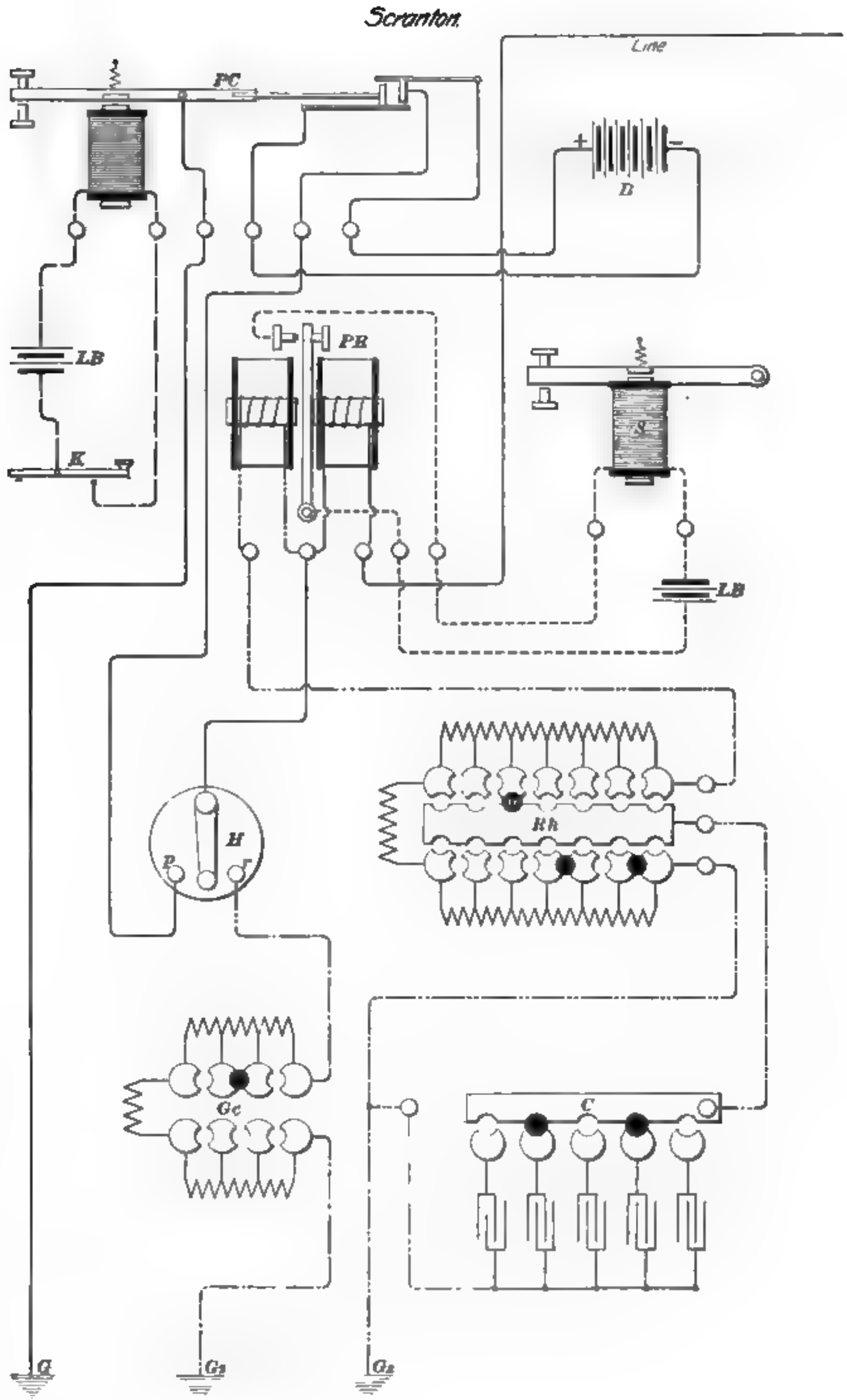


FIG. 43.

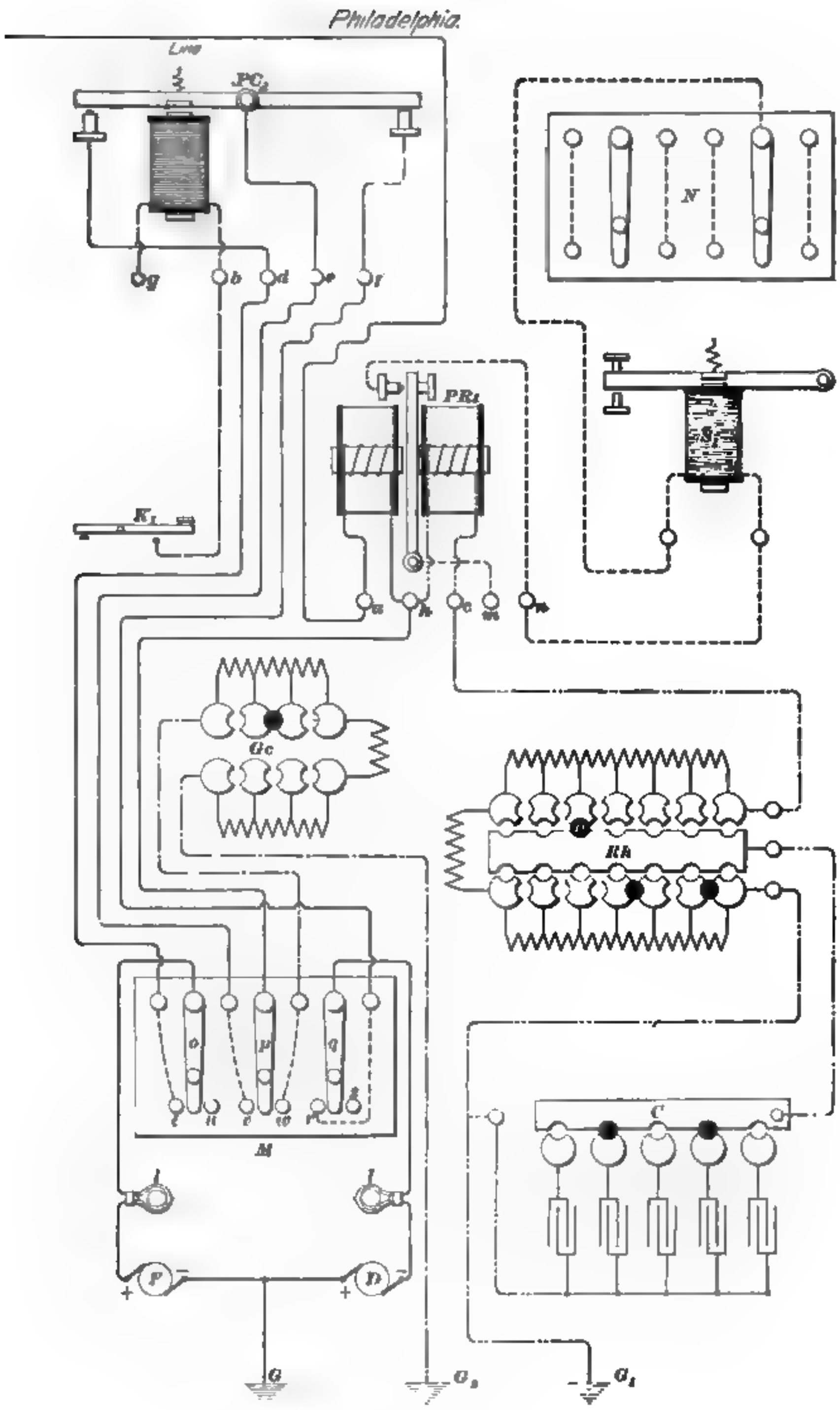
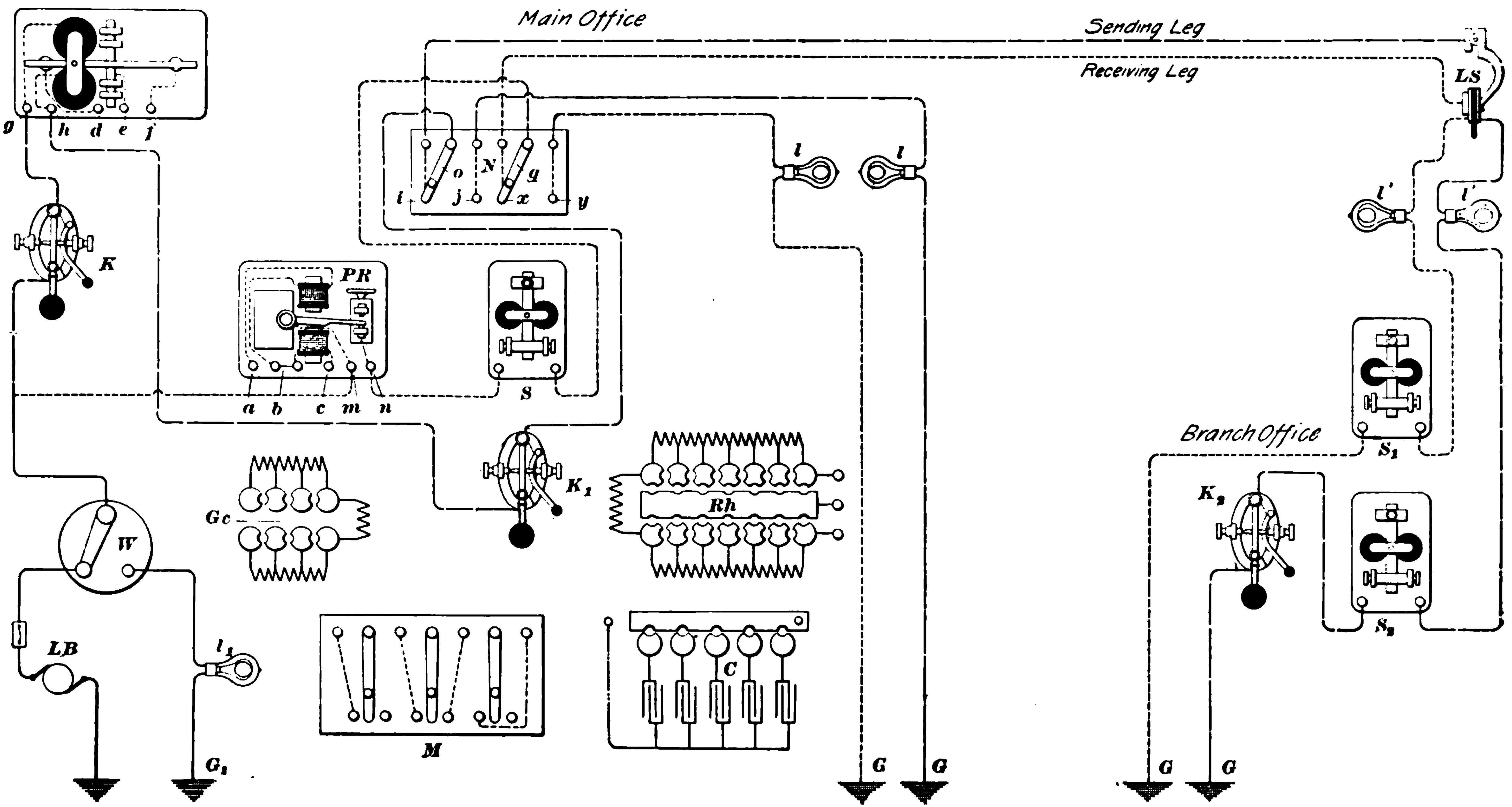


FIG. 44.



Main Office
Sending Leg
Receiving Leg
LS
l'
l'
g
h
d
e
f
K
PR
a
b
c
m
n
S
l
o
N
j
g
x
y
l
l
K1
Gc
Rh
W
LB
l1
G1
M
C
G
G
Branch Office
S1
K2
S2
G
G

FIG. 45.

of *Gc* should be equal to the internal resistance of the main battery *B*. *PC* represents a continuity-preserving pole changer suitable for use with gravity cells, such as already shown in Figs. 38 and 39. *K* is the sending key and *S* is the receiving sounder.

117. Polar Duplex Operated by Dynamos.—In Fig. 44 is shown the arrangement of the polar duplex when dynamos are used to operate the system. The walking-beam type of pole changer and the switch *M* replace the continuity-preserving pole changer and the simple switch *H* shown in Fig. 43 in which gravity main-line batteries were used.

In order to avoid confusion, the local receiving and sending circuits will be shown separately in Fig. 45. The contact buttons *u* and *z* on the switch *M*, Fig. 44, are idle, or insulated, and are used merely upon which to rest the arms *o* and *q* when it is desirable to entirely cut off the main-line dynamos *D* and *F*. When the system is in operation, the switch arms *o*, *p*, and *q* rest upon the buttons *t*, *v*, and *r*, respectively. When *p* rests upon the button *w*, the main circuit is connected through the ground coil *Gc* to the ground at G_2 instead of through the pole changer and dynamo *F* or *D* to the ground *G*. Thus, the polar relay is entirely disconnected from the home dynamos. This is the position of the switch arm *p* for balancing the system. The resistance of the circuit from *w* through the ground coil *Gc* to the ground G_2 is made equal to that of the circuit from *v* through the pole-changer contacts, one lamp *l*, and one dynamo to the ground *G*. *Gc* is practically equal in resistance to that of one of the lamps *l*. *N* is the form of switch used where a dynamo is employed to operate the local sending and receiving circuits.

118. Local Circuits Supplied From One Dynamo. In Fig. 45 is shown the connections for the sending and receiving circuits in Western Union offices where a 23-volt dynamo *L B* is used to supply current for the pole changer and sounders in both the sending and receiving sides of the

circuit. All sounders in the receiving side are controlled by the polar relay PR, and the pole changers and sounders in the sending side are controlled either by the key K or K_1 at the main office, or by the key K_2 at the branch office.

Sounders are included in the sending circuit at the branch office to enable the branch-office sending operator to hear his own writing and, also, to enable the main-office and branch-office operators to communicate with each other over the sending side. Sometimes a sounder is placed in the sending circuit at the main office, especially when the pole changer is adjusted so close that it is difficult for the main-office operator to read from the sounds made by it. The receiving side cannot well be used for communication between the main and branch offices, and, consequently, no keys are included in that side. For the convenience of the operator on the receiving side at the main office, the sending side is often extended over to the receiving table, where an extra key K_1 is inserted in the sending circuit. This enables the receiving operator to communicate, without leaving his desk, with the distant main office. Of course he cannot do this if the sending side is in use at that time. The pole-changer and sounder coils have the same resistance, usually 4 ohms, in each instrument. The branch-office loop, containing on the receiving side, or receiving *leg*, as it is called, the sounder S_1, and on the sending leg the sounder S_2 and the key K_2, is connected through a wedge and spring jack LS at the loop switchboard in the main office with the table switch N, as shown in the figure. When the switch arms o and q rest on the buttons i and x, respectively, the main-office sending and receiving circuits are in series with the branch-office sending and receiving circuits, respectively.

By means of various resistance lamps l', l', all loop circuits are made to have about the same resistance, so that any branch office may be connected through the loop switch to the duplex set, and the 23-volt dynamo will still furnish the proper amount of current. The branch-office loop may be readily cut off by moving the switch arms, o to j and

q to y. This substitutes two locally grounded circuits, each containing a lamp l, for the branch-office sending and receiving legs. These lamps l, l have the proper resistance, so that shifting the switch arm o from i to j and the switch arm q from x to y does not change the strength of the current. By means of the switch W, the 23-volt dynamo LB may be cut off and the circuit connected to the ground G_1 through the lamp l_1. This is convenient when there is a battery or dynamo in the circuit at the loop switch or elsewhere, or when another duplex set connected to this same dynamo is repeating into this set.

119. Several Loops in One Circuit.—It is practicable to connect several offices in one circuit on either or both the sending or receiving legs of a duplex or quadruplex circuit. In Fig. 46 the regular office set operated by local gravity batteries LB and LB_1 is shown connected with the two branch offices A and B through the loop switches LS and LS_1. IB and IB_1 are intermediate gravity batteries connected in the sending and receiving sides of the circuit, respectively. These batteries must have their poles so connected at the switch LS, as shown in the figure, that IB will be in series with LB, and IB_1 in series with LB_1, otherwise they will be opposing instead of assisting one another. In offices where only dynamos are used, there would be no gravity batteries at LB, LB_1, IB, and IB_1. The resistance of the loop circuits would then be so adjusted that the local-circuit dynamo, such as LB in Fig. 45, would furnish the desired amount of current. Or, two small dynamos of proper voltage used as intermediate batteries, one in place of IB and the other in place of IB_1, could be employed. In this case there would be no batteries at LB and LB_1.

With the switch arm O resting upon the contact button i, the sending leg may be traced from the ground G_3 through K_3, S_3, IB, LS, LB, the magnet of the pole changer PC, K, K_1, the switch arm O, i, LS_1, S_4, K, G_4, and through the ground back to G_3. With the switch arm Q resting on x, the receiving leg may be traced from the ground G_1

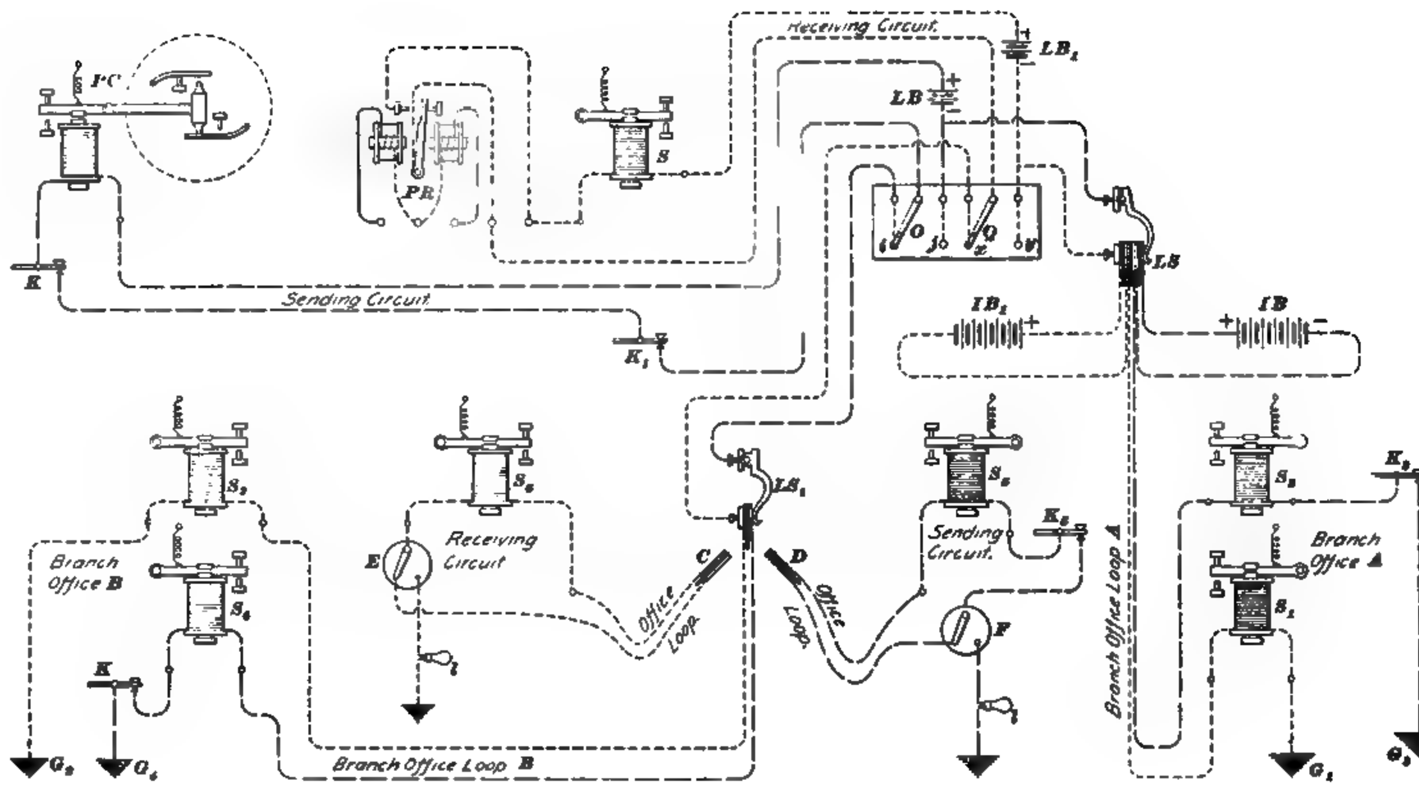

PC
PR
S
Receiving Circuit
LB
LB_1
O
Q
LS
IB_1
IB
K
Sending Circuit
K_1
S_3
Branch Office B
S_4
K
G_2
G_4
S_6
E
Receiving Circuit
Office Loop
C
LS_1
D
Office Loop
S_5
Sending Circuit
K_2
F
Branch Office Loop B
Branch Office Loop A
S_3
K_3
Branch Office A
S_1
G_1
G_3

FIG 46.

through S_1, IB_1, LS, LB_1, S, the contact points of the polar relay PR, the switch arm Q, x, LS_1, S_2, G_2, and through the ground back to G_1.

Extra main-office sending and receiving circuits may be easily included by inserting the wedge C in the spring jack LS_1 on the receiving side, and the wedge D on the sending side of the wedge already in the jack. The switches E and F must be turned to the left. By turning either or both of these switches to the right, either or both of the receiving and sending legs extending to the branch office B may be cut off. By turning the switch arm O to j and the switch arm Q to y, all the loop circuits are cut off, leaving only S and LB_1 in the receiving, and K, the magnet of PC, and LB in the sending sides.

TO BALANCE THE POLAR DUPLEX.

120. In explaining how to **balance the polar duplex,** we will consider that a line between Scranton and Philadelphia is to be worked on this system and that Scranton, Fig. 43, is the home office and Philadelphia, Fig. 44, is the distant office, and suppose that we desire to balance the home set.

1. *To Center Armature of Polar Relay.*—Scranton will first request Philadelphia to ground his circuit. Philadelphia will do this by turning the switch arm p to w, thus cutting off all source of current at Philadelphia by inserting the ground coil Gc between the polar relay and the ground in place of the pole changer and the dynamos. Then the home office will ground his set by turning the switch H to r, thus cutting off the battery at the home end. Now, with all source of current cut off, adjust the polar-relay armature until it will remain against either stop, or move with equal force from the middle position toward one side or the other. This adjustment, called *centering the armature of the polar relay*, is to make the pull due to the permanent magnetism equal on each side.

2. *To Obtain Resistance Balance.*—Having centered the armature, turn on the home battery, in this case by turning the switch *H* to *p*. If there is now more current in one winding of the differentially wound polar relay than in the other, the armature will be held more firmly against one contact point than against the other, which must be overcome by adjusting the amount of resistance in the artificial line by changing the plugs in the rheostat *Rh* until the armature will again remain against either contact point, or move with equal force toward one side or the other from the middle position, as before. When this is done, the resistance of the line and artificial circuits are equal. This adjustment is called the **resistance** balance. Although this is usually the case, still, strictly speaking, it is not necessarily the resistances of the two circuits that are made equal, but, rather, it is the magnetizing effects of the line and the artificial-line coils.

If the rheostat is incorrectly adjusted, the signals from the distant office may be too light in one position of the home key and too heavy, or "sticky," in the reverse position. Hence, it is important to test and, if necessary, to alter the adjustment of the rheostat until the incoming signals are equally good when the home key is open or closed. Furthermore, the incoming signals should still be good when dots are being rapidly made on the home key. The rapid manipulation of the home key alone may not show that the rheostat was improperly adjusted. This method of obtaining a resistance balance should always be followed, especially in wet weather and on poor wires.

3. *To Obtain a Static Balance.*—If the capacity of the artificial line does not balance that of the line, there will be a kick at the instant the home battery is reversed, due to opening or closing the home key. A kick indicates that the line and artificial line have not the same capacities, or that one charges and discharges more quickly than the other. To eliminate this kick, it is necessary to adjust the capacity of the condenser, or its point of connection with the rheostat, by means of the plug *o* until the kick disappears. The

best way to do this is to ask the distant office to cut in, that is, to shift the switch arm *p* from *w* to *v*, and to close his key K_1, Fig. 44. This will close the home (Scranton) polar relay *PR*. If the kick does not appear when the relay contact is closed, it surely cannot cause trouble at any other time, for that is the actual position of the home relay armature when the distant office is making a dot or dash and when the home relay armature must remain closed, that is, in contact with its front stop to which the local battery is connected. Hence, with the distant key closed, adjust the capacity of your condenser and then, if necessary, adjust the position of the plug *o* in the rheostat so as to retard or hasten the discharge from the condenser, until the kick disappears entirely. This adjustment is called the **static balance.** The nearer the peg *o* is placed to the end of the rheostat that connects with the artificial coil of the relay, that is, the less resistance that there is between the peg *o* and the relay, the quicker will the condenser charge and discharge.

121. Adjustment of a Battery Pole Changer.—The proper adjustment of the pole changer is very essential to the successful operation of the system in which it is used. The method of adjusting the clock-face pole changer, illustrated in Fig. 39, is as follows: Adjust the lever *n* by means of the limit screw *o* and the one below it, which is not shown in the figure, so that it will have a play of $\frac{1}{32}$ inch, which is about the same as is ordinarily given to a sounder, care being taken that the armature cannot strike the iron cores. Then, by means of the screw *o*, reduce this play to $\frac{1}{64}$ inch. This will hold the movable contact *e* on the forward end of the lever in its middle position. Now raise the screw *c* until the spring *d* barely touches *c*, being careful not to turn the screw *c* too far. Similarly, lower the screw *b* until the spring *a* barely touches *e*. Finally, raise the screw *o* until the lever has its working play of $\frac{1}{32}$ inch. The contact *e* in moving from one extreme position to the other should momentarily, in about its middle position, touch one spring

before parting from the other. If it leaves one before touching the other, the circuit will be momentarily opened. On the other hand, it must not remain in contact with both springs any longer than is absolutely necessary, because the battery is short-circuited from the instant *e* touches one spring until it parts from the other. This period during which the battery is short-circuited can be reduced almost to nothing by carefully adjusting the instrument.

The student should have no difficulty in adjusting the B. & O. pole changer, illustrated in Fig. 38, if he thoroughly understands the principle of this pole changer and the adjustment just explained.

122. Remarks Concerning Dynamo Pole Changers.—The dynamo walking-beam pole changer is apt to require more attention than any other one instrument in either the polar duplex or quadruplex system. The method of adjusting and caring for it is the same for both systems. The contact points of the dynamo pole changer cannot be adjusted as closely as those used with gravity batteries. The dynamo pole changer uses two dynamos of, say, 350 volts each, one positive and the other negative; whereas, the battery pole changer uses only one battery of 350 volts. With the dynamos there is a pressure of 700 volts tending to jump across the air-gap between the contact points. The introduction of dirt or the slightest jar between these two points will aid the electromotive force to establish an arc that acts as a fair conductor for the current, which at once flows through the beam from one dynamo to the other. In the gravity-battery arrangement, the highest pressure that can be short-circuited is 350 volts.

With the pole changer properly adjusted there is a spark at the break, but this legitimate spark is not nearly so harmful as the arc that hangs on when the instrument is so adjusted as to break improperly.

The tension of the spring may be so great that when the magnet releases the armature, the lever will fly to the other contact with such momentum that it rebounds more or less,

causing an arc to form at this insecure contact. An arc will also be formed if the lever is not promptly released. This inability to promptly release the lever may be due either to the trunnion being too tight or to the weak tension of the spring necessary when the local battery is too weak. The first may be remedied by properly adjusting the trunnion; the second, by strengthening the battery and increasing the tension of the spring.

123. Adjusting a Dynamo Pole Changer.—A dynamo pole changer may be properly adjusted in the following manner: First, be certain that the current through a 4-ohm pole changer is not less than 250 milliamperes. For fast work, a current of 275 milliamperes is not too strong. Then adjust the contact points so that you can scarcely hear your own signals on your own pole changer when you send on the key controlling it. Next adjust the tension of the spring so that the down stroke will be just a little heavier than the up stroke, and see that the trunnion is neither loose nor binding. The expert quadruplex attendant adjusts the pole changer almost entirely by sound, because sight adjustment, aside from the preliminaries, is very deceptive. When the pole changer has been adjusted to have minimum play, and gives at the same time low but distinct signals, the tendency to arc is reduced to a minimum.

With the pole changer adjusted to have a minimum play, a sounder is often connected in series with the pole-changer magnet and key in order that the operator may hear his own signals. When there is a sounder in series with the pole changer, it will be necessary to hold down the sounder lever while adjusting the pole changer in order to hear onl' the signals on the latter.

124. Mr. Willis H. Jones, in "The Telegraph Age makes the following remarks concerning the way some o] erators balance the polar duplex:

"Many operators adjust the cond[illegible] [illegible]hile the armatur of the home relay rests upon the [illegible]t point, an[illegible] seem to be satisfied when the kick [illegible] be heard.

They apparently forget that the 'sound' of the kick will disappear with a less amount of 'static' eliminated when the lever rests upon the back stop than when it rests upon the contact point, because in the former position the armature must cross the intervening space before it can produce a signal, while in the latter, it needs but make a start.

"Some operators believe that they are equally successful in equating by giving the armature a temporary bias in order to make it more sensitive, but no one will deny that by this plan the magnetic line balance is practically destroyed. Of course an endeavor is made to replace the lever in its former position, but such an action is plainly mere guesswork. If there are any that doubt this statement, let them try the plan on a poor wire, and, after having recentered the lever, as they believe, again ground the circuit at each end. It will be found that the experiment may have to be repeated many times before the armature can be found sufficiently 'centered' to remain where placed without further adjustment.

"To make matters worse, after having destroyed the magnetic equilibrium of the main and artificial line on the displaced armature, frequently attempts are made to mend matters by readjusting the rheostat while the distant office writes.

"When the apparatus is finally considered to be balanced, what are the actual conditions under which the operator is expected to work? Simply this—a practically lopsided relay, and a false line balance. It may work satisfactorily at the start, but the margin is very small, and a slight change in the atmospheric conditions may necessitate another balance."

125. The insulation of a line will vary with the weather, and the lower the insulation, the lower will be the apparent resistance and capacity of the line. Hence, a change in the weather that is sufficient to alter the insulation of the line may require a readjustment, to a greater or less extent, of both the rheostat and the condenser. This remark applies

with even more force to a quadruplex than to a duplex circuit, and the student should not forget this fact when he is at work on such systems. Polar relays on duplex circuits require 25 milliamperes to properly work them.

BRIDGE DUPLEX SYSTEM.

126. The bridge system shown in Fig. 47 is similar in its action to a Wheatstone bridge. *S* is a rheostat so arranged that, as the lever is turned upwards, resistance is taken out of the *a c* arm of the bridge and is added to the *a d* arm, and *vice versa* if the lever is moved in the other direction. The four arms of the bridge are *a d*, *a c*, $d G_1$, and

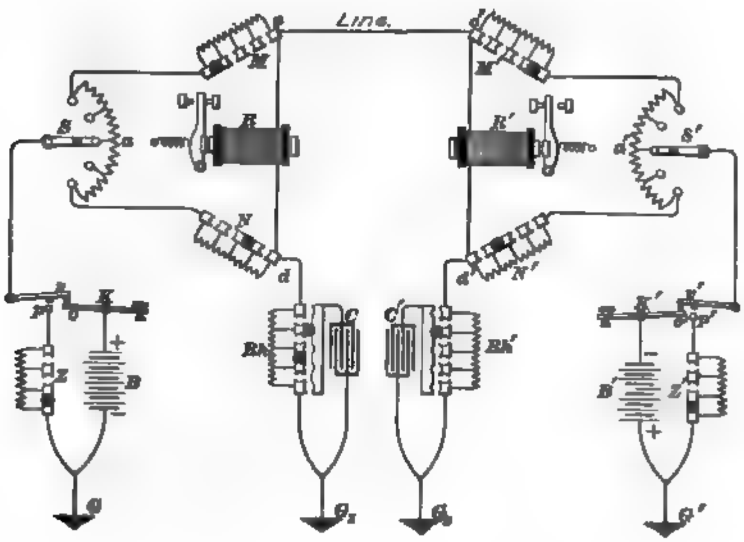


FIG. 47.

from *c* through the line and apparatus at the other station to the grounds G' and G_2. Hence, the resistance of the artificial line at each end must be equal to the resistance of the line wire plus the resistance from the distant end of the line to the ground through the apparatus at the distant

station, assuming, as is usually the case, that the resistance of ac is equal to that of ad. In any case, the following proportion must be satisfied: Resistance of ac : resistance of ad :: line resistance + resistance from c' through all paths at right-hand station to grounds G' and G_1 : resistance of the artificial line dG_1. When this is the case, there is no difference of potential between the points d and c.

127. M, M', N, and N' are adjustable resistances and K represents a continuity-preserving transmitter. When the key is pressed down, the lever o lifts the lever v off the contact point p, momentarily short-circuiting the battery in order to avoid opening the circuit between the ground G and the line. In practice, the continuity-preserving transmitter illustrated in Fig. 5 may be employed on a land line. The adjustable resistance Rh and condenser C constitute an artificial line, and Z is a resistance that is adjusted to equal the internal resistance of the battery B.

The resistance Z, key K, and battery B are arranged and used in the same manner as already explained in connection with the Stearns differential duplex. The apparatus and connections at the two stations are similar.

128. From Fig. 47, it will be seen that if ac bears the same relation to ad that the circuit from c through the line and apparatus at the distant station to ground bears to dG_1, then the relay R, which in this case corresponds to the galvanometer in a Wheatstone bridge, will not be affected by the outgoing current from the battery B, for the same reason that the galvanometer in the Wheatstone bridge will not be deflected when the bridge is balanced. If the key K' at the distant station is pressed down and K is up, i. e., open, some current will pass along the line and at the point c will divide, a part of it passing through and operating the relay R. The position of the key K will in no wise affect the operation of the relay R, because the position of the key K does not alter the resistance of the circuit between a and G. Thus the relay at one station will be operated only by the key at the distant station.

129. Adjustment of resistances is made in $a\,c$ and $a\,d$, first by the resistance boxes M and N, and, finally, by the rheostat S. If the resistance from c through the line and apparatus at the distant station to the ground is 4,000 ohms, then a resistance of 1,000 ohms in $a\,c$, 2,000 in Rh, and 500 in $a\,d$ would properly balance the bridge. The connection between the condenser C and the resistance box Rh should be adjusted until the artificial line charges and discharges in the same manner as the line, so that no momentary kick would be made by the relay.

130. Comparison Between Bridge and Differential Duplex.—The bridge duplex is superior to the differential duplex in that it requires less condenser capacity in the artificial line, and the resistances and condensers can be more readily adjusted to suit the varying conditions of the line. However, the bridge duplex is inferior to the differential duplex in that it requires more battery power to produce the same strength of current in the relay. This inferiority of the bridge duplex has excluded it from use on long land circuits. On short lines of low resistance, where an excessively high electromotive force would not be required and when batteries of low resistance can be used, it is preferable to the Stearns differential duplex, but it is not preferable to the polar duplex.

131. Bridge Duplex Used on Submarine Cables. The bridge principle is used wherever submarine cables are duplexed; but, while the principle is the same, the apparatus used is quite different from that shown in this figure. The bridge duplex, as applied to submarine cables, will be explained in connection with submarine telegraphy.

MORRIS SINGLE-BATTERY DUPLEX.

132. The **Morris single-battery duplex,** invented by Mr. R. H. Morris of the Western Union Telegraph Company, requires a main-line battery only at one end. It is a

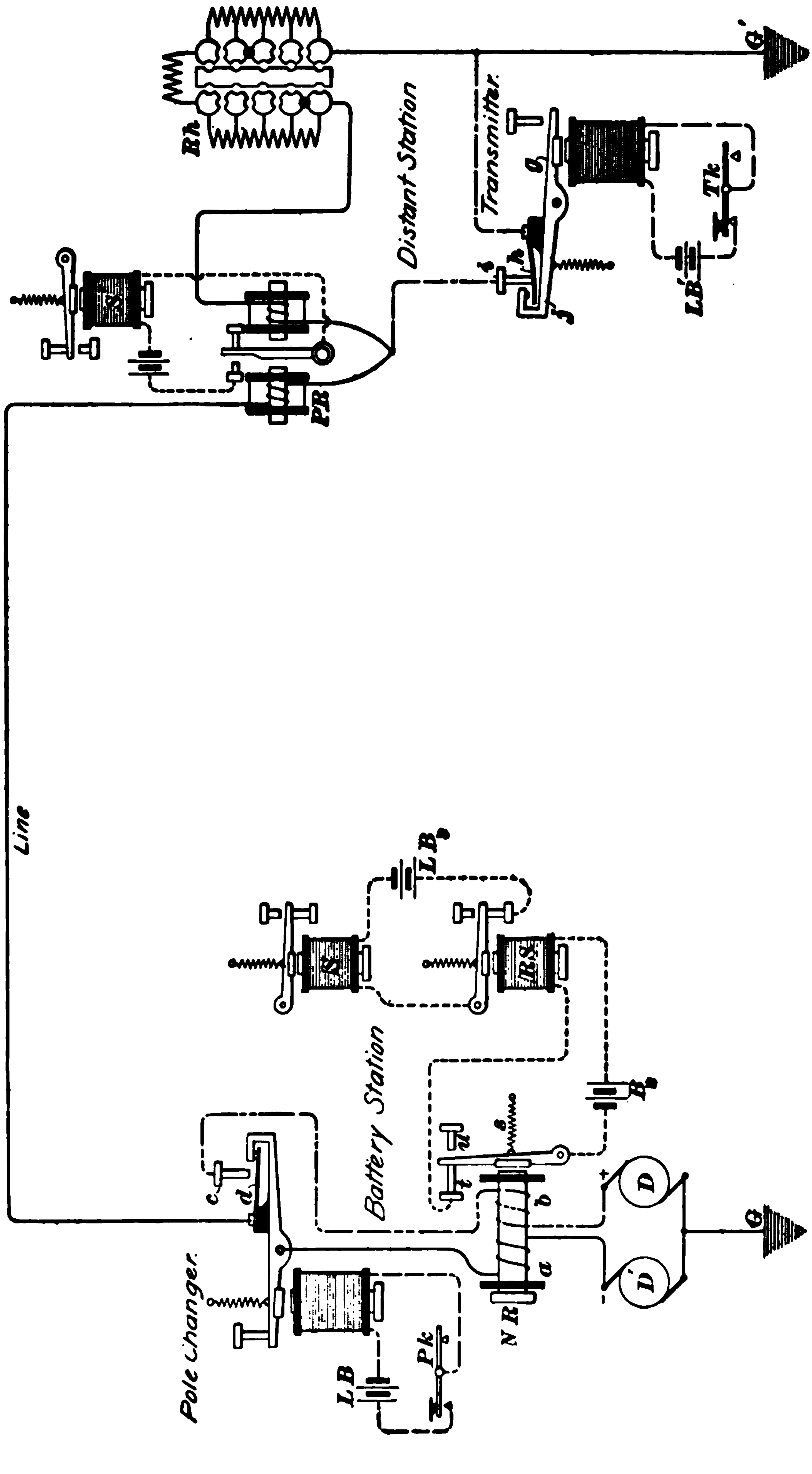

Distant Station
Transmitter
Rh
PR
S
G'
Tk
LB'
Line
Battery Station
Pole Changer
LB
Pk
NR
RS
D
D'
G

FIG. 48.

great improvement over a somewhat similar system, called the Edison-Smith duplex, and has proved to be one of the most useful and economical systems for short lines; it is considerably used, especially in New York city and the immediate vicinity.

133. The **general arrangement** of the apparatus is shown in Fig. 48. The various instruments shown are the same as those used in the duplex and quadruplex systems. It will be noticed that an ordinary continuity-preserving transmitter is used at the battery station as a pole changer. This instrument is used in preference to one of the walking-beam pattern in order that the benefits of a continuity-preserving device may be obtained. Where a low electromotive force is used, a transmitter connected as a pole changer may be beneficially substituted for the ordinary dynamo walking-beam pattern, as the tendency to spark will be small.

134. One distinctive feature of the Morris duplex lies in the use of a differential relay, called a **neutral relay.** However, this relay is not used differentially, and is practically a single relay because the current never flows differentially through the two coils. Thus, one current does not neutralize the effect of the other. Moreover, the direction in which the cores are magnetized is never reversed. The coils are so wound and connected that when current from the negative dynamo D' circulates through the coil a, the iron is magnetized in the same direction as when current from the positive dynamo D circulates through the coil b. When the pole changer shifts the line from one coil of the neutral relay to the other coil, there is a moment when the two dynamos are in series and no current flows over the line. In this condition of affairs, there is quite a strong current through both coils of the neutral relay, but the current is in such a direction through the two coils as to preserve the existing direction of the magnetization of the relay. Hence, the magnetization of the neutral relay does

not even fall to zero, much less does it reverse when the pole changer is in operation. Consequently, the magnetization produced at reversal tides the relay over the period of reversal and thus avoids the kick that is so objectionable.

135. *Rh* is an adjustable resistance. When the transmitter at the distant station is closed, this resistance and one coil of the polar relay *PR* are short-circuited and the line is connected through one coil of the polar relay and through the transmitter to the ground *G'*. When the transmitter is open, both coils on the polar relay and the resistance *Rh* are connected in series between the line wire and the ground *G'*. The resistance in *Rh* is made so high that when it is in the circuit, the current is reduced to one-fourth the strength that it possesses when the transmitter is closed. But both coils of the polar relay are in series when the transmitter is open and the current flows through the two coils in such a direction that they help each other, and the magnetization produced is still sufficient to operate the polar relay when the current is reversed by the pole changer at the battery station.

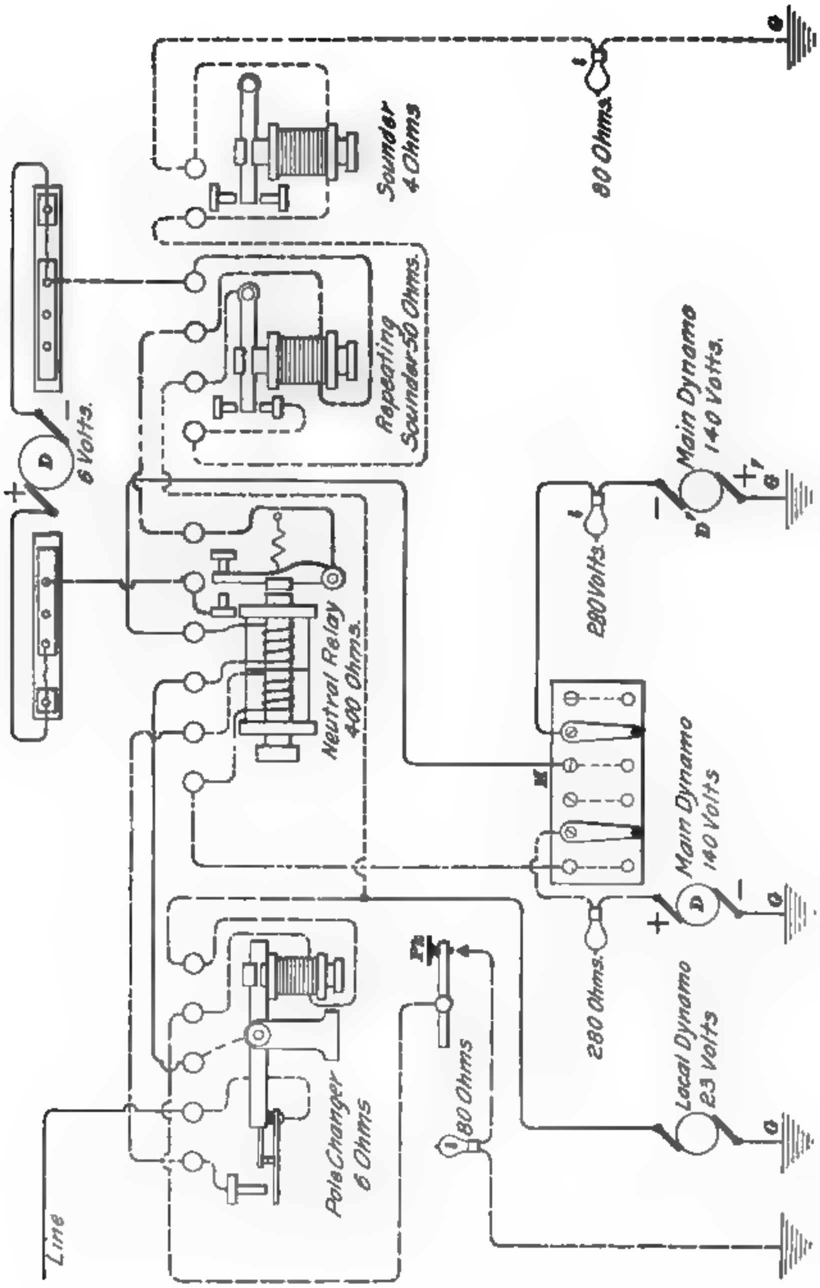
The spring of the neutral relay is so adjusted that when the transmitter at the distant station is closed, the current is strong enough to overcome it and to attract the armature. But when the distant transmitter is opened the resistance *Rh* is included in the circuit, and consequently the current is reduced to one-fourth its previous strength, and the magnetism produced in the neutral relay is not sufficient to overcome the spring, and, hence, the armature is released. Therefore, the neutral relay can be closed only by increasing the strength of the current to four times its smaller value and its operation is entirely independent of the direction of the current. On the other hand, the polar relay is operated by reversing the direction of the current and is independent of the strength of the current used.

136. Arrangement of Sounders.—At the battery station, a repeating sounder *R S* has its circuit closed when the relay armature is against its front stop, and the ordinary,

or reading, sounder *S* has its circuit closed when the armature of the repeating sounder is against its front stop. The arrangement of these two sounders at the battery station is such as to avoid any danger of a false signal when the pole changer short-circuits the two dynamos through both coils. When the distant transmitter is closed, causing the neutral relay armature to rest against the front stop *t*, the increase in the magnetization of the neutral relay, due to the short-circuiting of the dynamos, can do no harm. Furthermore, experience with this duplex has shown that, even when the distant transmitter is open, the increment of current in the neutral relay, when the two dynamos are short-circuited, does not produce a false signal. This may be due to the fact that the duration of the short-circuiting is much less than the time required for the second coil of the neutral relay, which is empty, to build up from zerô. Moreover, it would be necessary, before a false signal could be produced on the sounder *S*, for the armature of the neutral relay to move from the back stop *u* to the front stop *t* and for the armature of the repeating sounder to also move from its back to its front stop. This movement requires time. Whatever may be the true explanation, the short-circuiting at the pole changer is so brief that no false signals are produced. It is a disputed point as to whether a repeating sounder is necessary. However, the apparatus was originally set up that way and it has never been changed.

OPERATION.

137. Both Keys Open.—Let both keys *Tk* and *Pk* be open, then the armature of both relays *NR* and *PR* will be resting against their back stops and the sounders *S* and *S'* will be open. The negative dynamo *D'* will be sending current through the coil *a*, pole changer, line, both coils of the polar relay *PR*, the resistance *Rh*, ground plate *G'*, and back through the ground to the negative dynamo *D'*. The direction of this current is such that the polar relay is held


Sounder
4 Ohms
80 Ohms
Repeating
Sounder 50 Ohms.
6 Volts.
Neutral Relay
400 Ohms.
Main Dynamo
140 Volts.
280 Volts
Main Dynamo
140 Volts
280 Ohms.
Local Dynamo
23 Volts
Pole Changer
6 Ohms
80 Ohms
Line

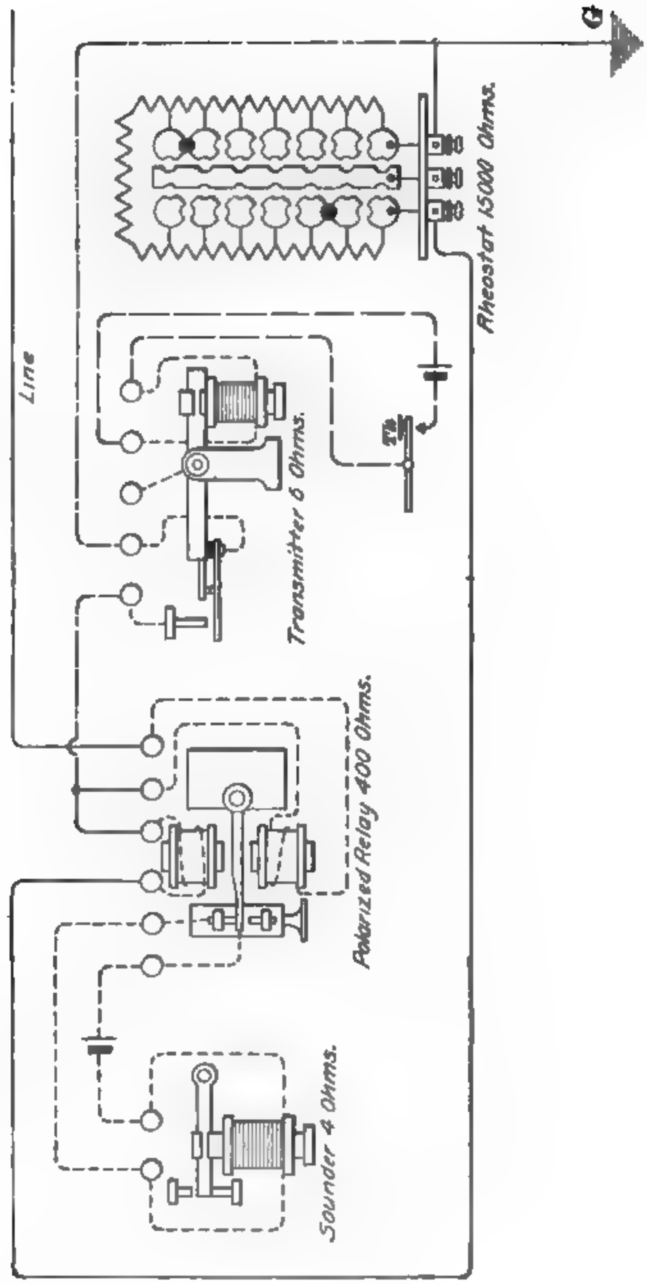

G
Line
Rheostat 15000 Ohms.
Transmitter 6 Ohms.
Polarized Relay 400 Ohms.
Sounder 4 Ohms.

FIG. 50.

open, and because the resistance *Rh* is in the circuit, the strength of the current is not sufficient to overcome the retractile spring *s* of the neutral relay; hence, the neutral relay is also open.

138. Key *Pk* Closed.—Let the key *Pk* be closed. This will close the pole changer, thus shifting the line from the negative dynamo *D'* to the positive dynamo *D* and reversing the direction of the current throughout the circuit. The neutral relay will not be affected, because the strength of the current is the same as before, but the polar relay will be closed. Hence, by closing the key *Pk* at the battery office, a signal is produced at the distant office only.

139. Both Keys Closed.—Suppose that while the key *Pk* is closed the key *Tk* is also closed This will cause the transmitter to close and short-circuit the resistance *Rh* and one coil of the polar relay, while the current will increase to four times its former strength. Although there is now only one coil of the polar relay in the circuit, still the current has been sufficiently increased in strength to more than make up for the fewer number of turns in the coils of the polar relay; moreover, closing the key *Tk* does not reverse the direction of the current. Hence, the polar relay is not affected and remains closed as long as the battery-station key *Pk* remains closed. But increasing the current to four times its former value closes the neutral relay *NR* at the battery station. Hence, both relays are closed when the two keys are closed.

140. Key *Tk* Closed.—If now the key *Pk* be opened, *Tk* remaining closed, the line will be shifted from the positive to the negative dynamo. This will reverse the direction of the current through the circuit, without causing any change in its strength, and, hence, only the polar relay will be opened. Therefore, the key at one station controls only the relay at the other station, and the operation of a key at one station does not interfere with the signals that are being received by the relay at the same station.

141. To Balance Morris Duplex.—The Morris single-battery duplex is balanced at the battery station by simply adjusting the retractile spring of the neutral relay so that the armature will properly respond to the signals from the distant station, at the same time that the battery-station key is being operated. The polar relay at the distant station requires no adjustment after its armature has been properly centered in the manner explained in Art. **120.** The resistance *Rh* is so adjusted as to make the maximum current four times as great as the minimum.

142. The **actual connections** of the apparatus at the two offices are clearly shown in Figs. 49 and 50. The two arms of the switch *M* in Fig. 49 are turned to the left when the apparatus is in use. The 50-ohm repeating sounder is supplied with current from a 6-volt dynamo and the other local circuits are supplied, as usual in Western Union offices, from a 23-volt dynamo. Lamps having the proper resistance are connected in the various circuits to help regulate the strength of the current. No primary batteries are used at the battery station, and at the distant office only enough gravity cells to operate the transmitter and the sounder are required.

DIPLEX.

143. The **diplex** is a system of telegraphy by which two messages may be simultaneously transmitted in the same direction over one wire. The form described here should be thoroughly understood, for it is an essential feature of the quadruplex systems.

144. The principle of the diplex may be readily understood by the help of Fig. 51, in which *P R* is a polarized relay; *N R*, a neutral relay, so called because its operation depends on *an increase in the strength of the current and not on the direction of the current; P C*, a pole changer; and *T* a transmitter. The transmitter is so connected that when the key is open, only one cell *B'* is connected between the wires *d*

and *e*. When the key is depressed, the lever *a* first touches the lever *b*, thereby short-circuiting, momentarily, the battery *B*, which consists of three cells, before it lifts *b* off *c*. When the lever *a* has lifted *b* off *c*, the two batteries *B* and *B'* are connected in series, making one battery of four cells across the two wires *d* and *e*. Hence, the number of cells in the circuit has been increased from one to four; consequently, with the same resistance in the circuit, the strength of the

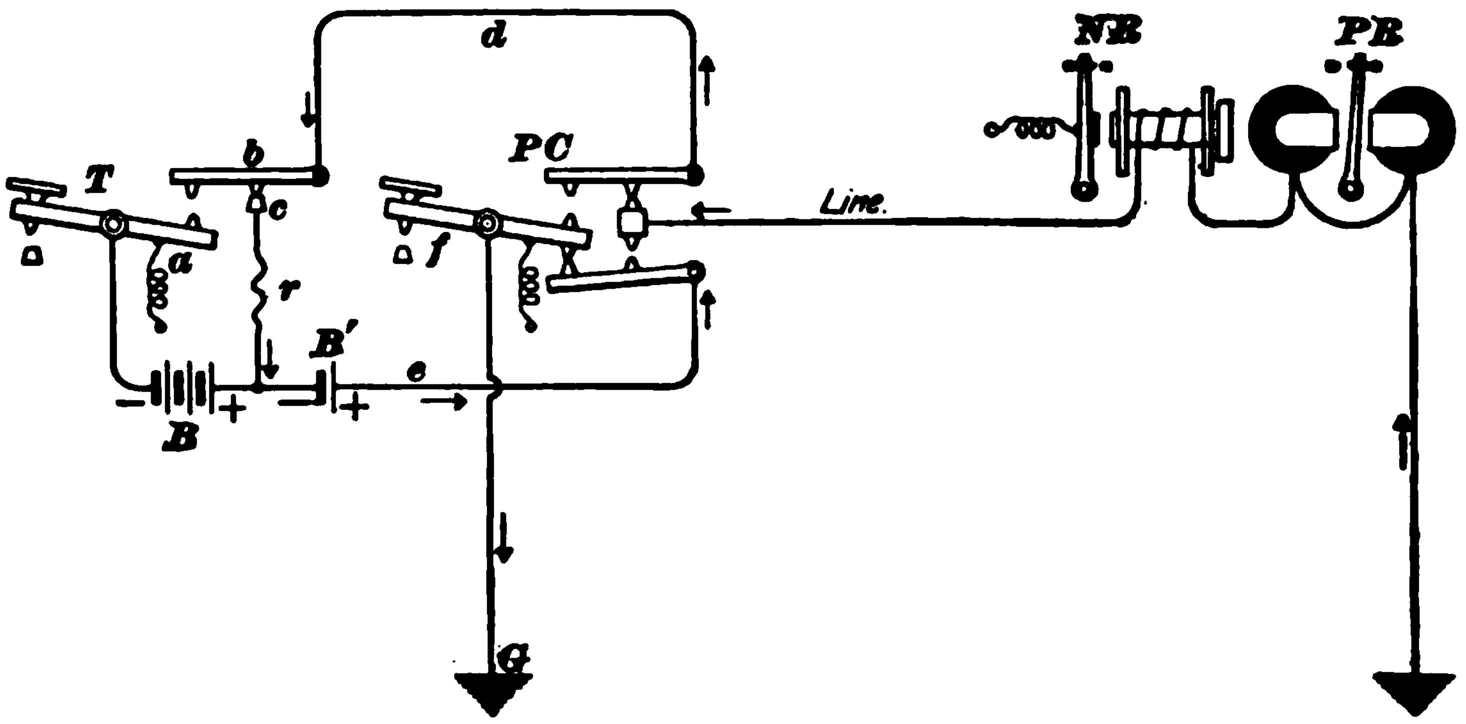


FIG. 51.

current will be four times as great as before. If the weaker current has a strength of 1 unit, then the stronger current will have a strength of 4 units. That is, the ratio of the two currents is 1 to 4. In order to keep the resistance of the circuit the same whether *B* is cut in or out, it is necessary to insert the resistance *r*, which is equal to the internal resistance of the battery *B* in the circuit when the battery *B* is cut out.

145. When the key *f* of the pole changer *PC* is open, that is, up, the line is connected to the wire *d*, and the ground *G* to the wire *e*. When the key is depressed, these connections are reversed. Hence, the pole changer, when operated, reverses the polarity of whatever battery happens to be connected by the transmitter *T* across the two wires *d* and *e*. The operation of the transmitter varies the current from 1 to 4 units, or *vice versa*, and the pole changer merely

reverses the direction of this current through the line whether it be 1 or 4 units. Thus the transmitter and the pole changer do their work independently of one another.

The student should clearly understand the action of these two instruments when they are combined in this manner. There are four possible positions of these two keys. If the student does not clearly understand that the operation of the pole changer does not affect the strength of the current, and that the operation of the transmitter does not affect the direction of the current in the line, he should draw on a separate piece of paper the three other possible positions of the two keys and note the strength and direction of the current in the line in each case. The tongue, or armature, of the polarized relay will move whenever the direction of the current is reversed, no matter whether the strength of the current is 1 unit or 4 units. The reversal of the 4-unit current will perhaps make the polarized relay operate more vigorously than will the reversal of the 1-unit current, but the 1-unit current will operate it and the intensity of the click of the sounder that is controlled by the polar relay will be the same in either case.

146. The neutral relay, however, will tend to attract its armature no matter in which direction the current flows through it, and if the current is only strong enough to overcome the retractile spring, the relay will close its local circuit. The spring is adjusted so that the magnetism produced by the 1-unit current will not be strong enough to overcome it, but the magnetism produced by the 4-unit current will readily overcome the spring and close the local circuit. Hence the message sent by the operator at the transmitter T is received by the operator at the neutral relay NR, and the message sent by the operator at the pole changer PC is received by the operator at the polarized relay PR. Furthermore, these two messages do not interfere with each other when the apparatus is properly adjusted.

147. Elimination of False Signals.—If the pole changer reverses the direction of the current while the

4-unit current is flowing, in which case the neutral relay is closed, the neutral relay tends to release its armature at the instant of reversal, because when the whole battery is reversed, and, consequently, the direction of the current through the neutral relay is reversed, the magnetism of the neutral relay must fall to zero before it can increase to its normal strength in the opposite direction. If the interval of no current in the neutral relay, which lasts while the battery is momentarily short-circuited, is sufficiently prolonged, a mutilation of the signal, or a **false signal** as it is called, will be produced that will seriously interfere with the successful operation of the system However, by adjusting the pole changer so that the interval of no current in the line and relay is as short as possible, and, furthermore, by using a repeating sounder that is closed on the back stop of the neutral relay, and an ordinary sounder that is closed, in turn, on the back stop of the repeating sounder, the tendency to produce false signals can be overcome. When the local circuit is connected to the back stop instead of to the front stop of the neutral-relay armature, a reduction in the magnetizing force of the relay that will allow the armature to momentarily break away from the front stop will not produce a false signal by closing the ordinary sounder circuit, *unless the time interval is sufficient* for the relay armature to cross the gap between the front and rear stops, and to make contact with the rear stop. Furthermore, both the repeating sounder and the ordinary sounder require some time before their magnetism can build up from zero to a strength sufficient to start the movement of their armatures. Hence, if the relay armature does momentarily close the repeating-sounder circuit, the duration of contact may be too short to allow the repeating sounder, in turn, to close the circuit of the ordinary sounder, and even if this should happen it may last so short a time that the ordinary sounder cannot build up and make a signal.

148. Whenever a repeating sounder is connected to the back stop of a relay and the signals are to be read by sound,

then a second sounder must be used, and the second sounder must be connected to the back stop of the repeating sounder, otherwise, the signals will be reversed; that is, dots and dashes will be transformed into spaces, and *vice versa*. This second sounder is frequently called the **reading sounder.**

QUADRUPLEX SYSTEM.

149. The principle of all **quadruplex systems** in which two messages are sent in each direction simultaneously over one line wire is about the same. In the Stearns duplex system, the differential relay responded only to signals sent from the distant office; the connection and disconnection of the home battery did not affect the home relay because it was differentially wound. In the polar duplex, the polar relay at the home office responded to the reversals of the distant battery but not to the reversals of the home battery, because the polar relay was also differentially wound. In the diplex system that has been described, it was shown how one message could be transmitted by increasing and decreasing the strength of the current, independent of its direction, while another message is being sent by reversing the direction of the current, independent of its strength. If in the diplex already explained, we wind both the neutral and polar relays differentially and connect them at the home station, as shown in Fig. 52, the operation of the home transmitter and pole changer will not affect these relays. This is evidently a combination of the principles involved in the Stearns duplex, the polar duplex, and the diplex. The student should thoroughly understand each of the systems mentioned in order to comprehend the complete quadruplex systems that will follow. As in the duplex systems, the artificial line is here made equal in resistance and capacity to the line wire. In this figure, whatever current finds its way from the battery, through the transmitter and the pole changer, to the point *h* will there divide equally. One half will flow through the coil *n* on the neutral relay, the coil *p* on the

polarized relay, the line, the ground plate G_1, the ground, and the ground plate G back to the battery; the other half will flow through the coils *m* and *o*, the artificial line, ground plate G_2, the ground, and the ground plate G, back to the battery. The coils *n* and *p* are called the *line coils*, and the coils *m* and *o*, the *artificial-line coils*. The two relays are differentially wound and so connected that current flowing from the home battery, dividing at *h*, and flowing equally through the line and artificial-line coils will not magnetize or *affect either relay, no matter what may be the strength or direction of this current.* The coil *m* neutralizes the effect of the coil *n*, and *o* neutralizes *p* when the current for all the coils comes from the home battery and divides equally at *h*.

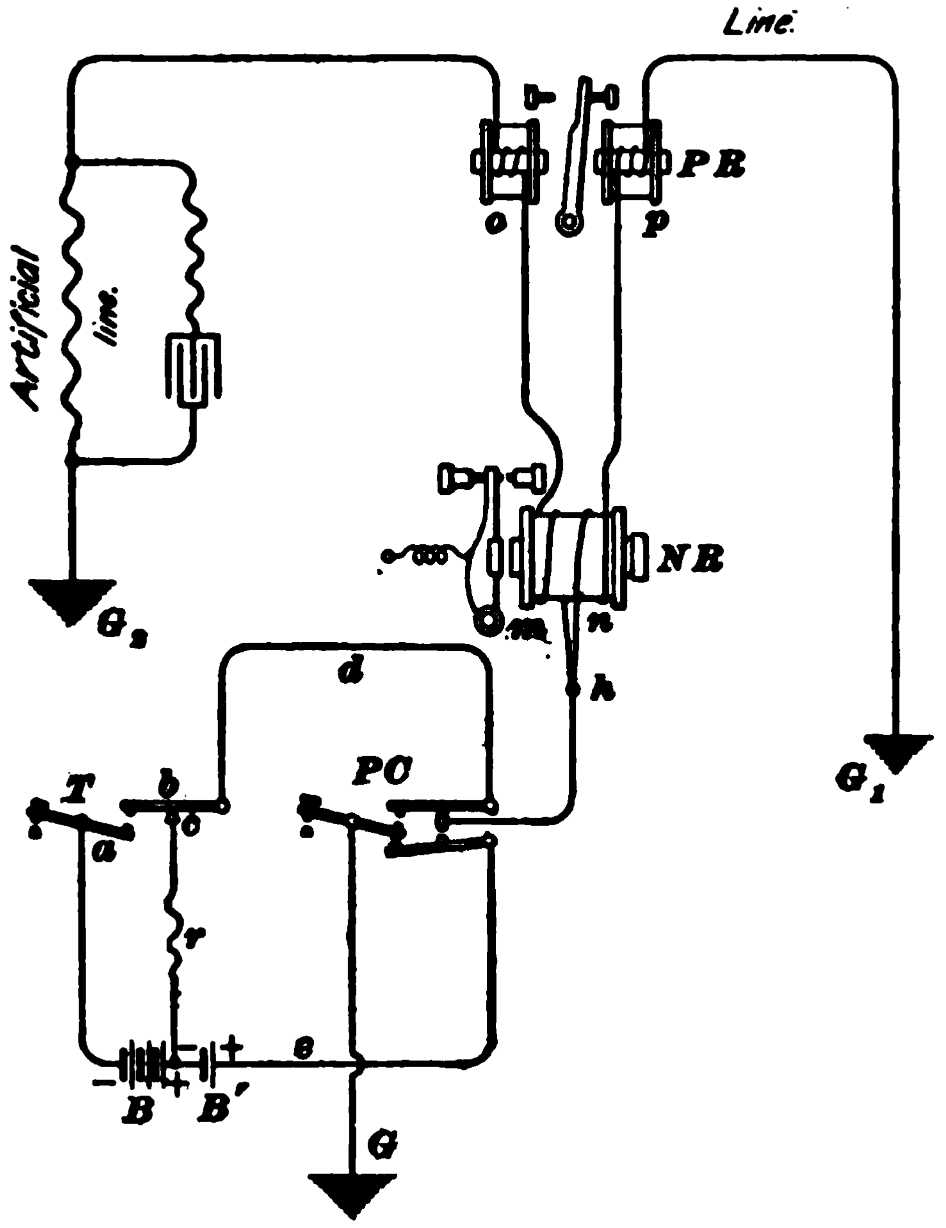


FIG. 52.

150. In the next step, which is illustrated by Fig. 53, a neutral relay NR_1 and a polar relay PR_1 are connected at the distant station in series with the line. In this figure the resistance and capacity of the artificial line are adjusted until the current from the battery at the west station divides into two equal parts at the point *h* and passes in opposite directions in the two coils of *N R* and *P R*. Such being the case, it is evident from preceding explanations, that the operation of the pole changer and transmitter at the west

station will not operate the neutral relay NR nor the polar relay PR at that station. The current that finds its way over the line and through the neutral and polar relays NR_1 and PR_1 at the eastern station is free to operate those relays, provided it has the proper strength and direction. If the line current is strong enough, it will close the neutral relay NR_1, no matter what its direction may be; and the same current will close the polar relay PR_1, if it flows in the proper

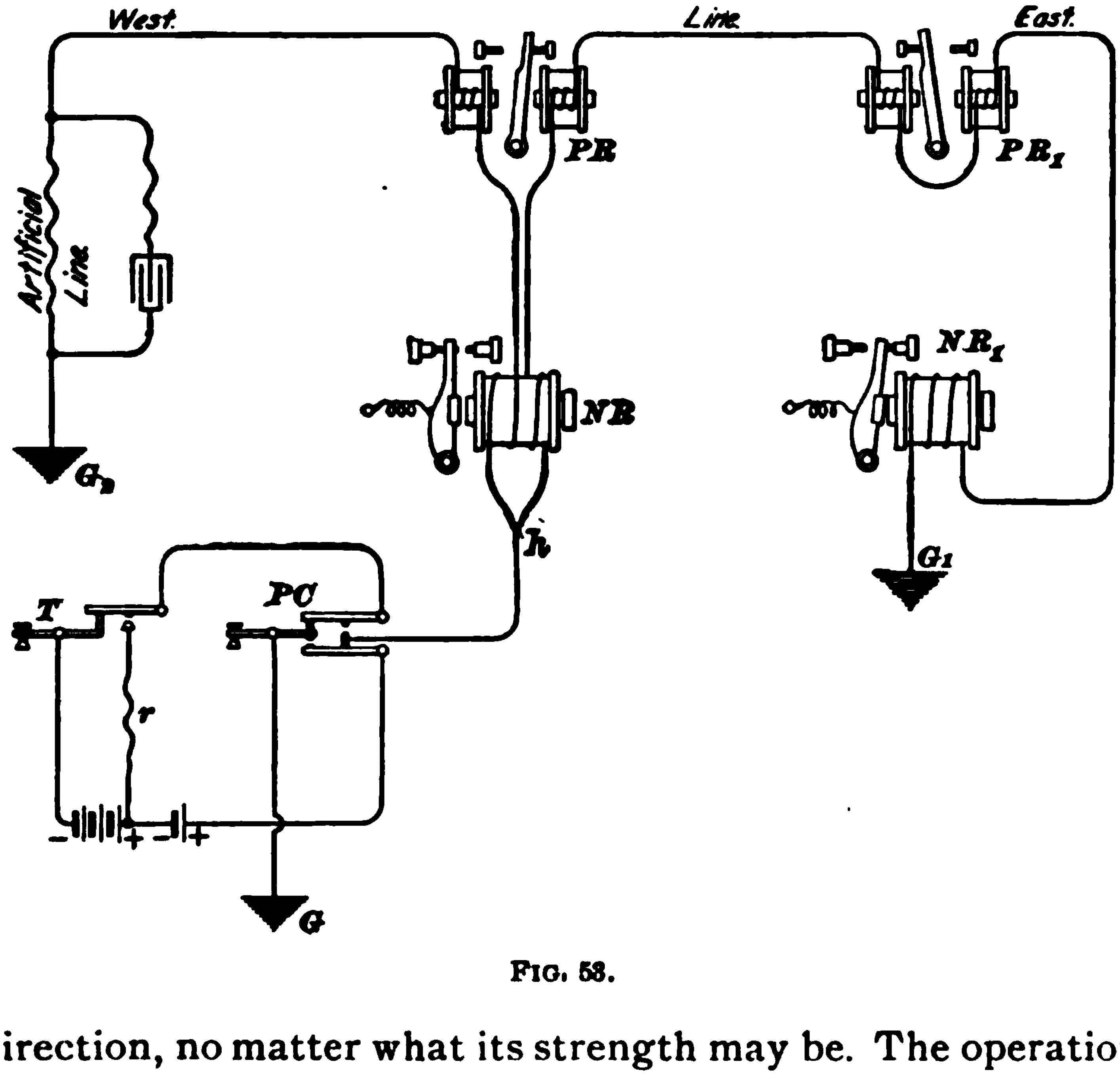


FIG. 58.

direction, no matter what its strength may be. The operation of the pole changer PC will not affect PR, because the latter is differentially wound, nor will it affect the neutral relay NR or NR_1, because merely a change in the direction of the current will not operate a neutral relay. Hence the only relay affected by the operation of the pole changer PC is the polar relay PR_1 at the distant station. The operation of the transmitter T will not affect NR because the latter is differentially wound, nor will it affect PR or PR_1, because merely

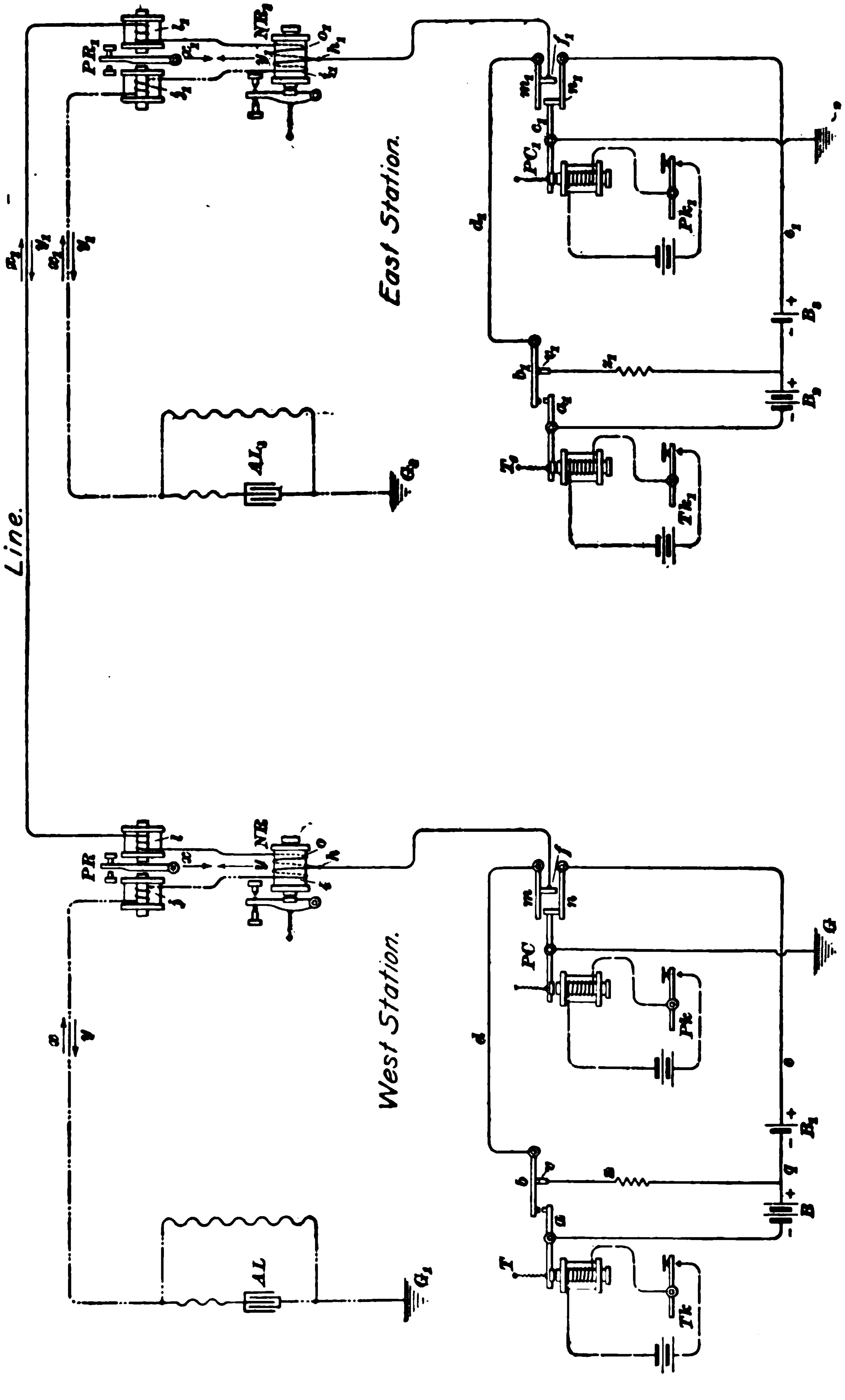


FIG. 54.

an increase or decrease in the current will not change the polarity of a polar relay. Hence the only relay affected by the operation of the transmitter T is the neutral relay $N R_1$ at the distant station. Therefore, one operator at T and another at $P C$ may send messages simultaneously, the message sent at T being received by an operator at $N R_1$ and the message sent at $P C$ by an operator at $P R_1$.

151. The next step consists in arranging the apparatus in exactly the same manner at both ends, so that two messages may be sent simultaneously in each direction without interfering with each other. This arrangement is shown in Fig. 54. In order to have a clear diagram to use in explaining the system, the apparatus in this figure has been reduced to as simple a form as possible, and all local-sounder connections have been omitted. Diagrams showing the practical form and arrangements of the instruments will be given later. The arrangement of apparatus at the two ends is exactly similar, and the four relays are differentially wound. The artificial line $A L$ is so adjusted that the resistance from h through $A L$ and G_1 to G equals the resistance from h through the line coils o and l and the line to the ground at the east station. $A L_1$ is similarly adjusted, so that the resistance from h_1 through $A L_1$ and G_3 to G_2 equals the resistance from h_1 through the line coils o_1 and l_1 and the line to the ground at the west station. The resistance of the ground return should, strictly speaking, be included in the above circuits, but it can usually be neglected without appreciable error. The battery B has twice the electromotive force of B_1, as is indicated, by giving B twice as many cells as B_1. Hence, if B_1 has an electromotive force of 100 volts, B will have an electromotive force of 200 volts. When B_1 alone is connected between the wires d and e, the electromotive force will be 100 volts; when both B and B_1 are connected in series between d and e, the electromotive force will be 300 volts. Hence, if the strength of the current in the first case is represented as 1 unit, the current in the second case will be 3 units.

TABLE 3.

No.	Keys: West PK	Keys: West LK	Keys: East PK_1	Keys: East LK_1	Pressure in Volts: k West	Pressure in Volts: k East	Current in: West AI	Current in: Line I	Current in: East AI_1	Effective Current: West, Relays VR and LR	Effective Current: East, Relays VR_1 and PT_1	Relays Operated: West LR	Relays Operated: West NR	Relays Operated: East PR_1	Relays Operated: East NR_1
1	Open	Open	Open	Open	100	100	$\frac{100}{R}(x)$	0	$\frac{100}{R}(x_1)$	$\frac{100}{R}(x\,AI)$	$\frac{100}{R}(x_1\,AI_1)$	Open	Open	Open	Open
2	Closed	Open	Open	Open	100	100	$\frac{100}{R}(y)$	$\frac{200}{R}(y+x_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(y\,L)$	$\frac{100}{R}(x_1\,L)$	Open	Open	Closed	Open
3	Open	Closed	Open	Open	−100	−100	$\frac{300}{R}(x)$	$\frac{200}{R}(x+y_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(x\,AI)$	$\frac{300}{R}(y_1\,I)$	Open	Open	Open	Closed
4	Closed	Closed	Open	Open	+300	100	$\frac{300}{R}(y)$	$\frac{400}{R}(y+x_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(y\,I)$	$\frac{300}{R}(x_1\,I)$	Open	Open	Closed	Closed
5	Open	Open	Closed	Open	−100	+100	$\frac{100}{R}(x)$	$\frac{200}{R}(x+y_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(x\,I)$	$\frac{100}{R}(y_1\,L)$	Closed	Open	Open	Open
6	Closed	Open	Closed	Open	+100	+100	$\frac{100}{R}(y)$	0	$\frac{100}{R}(y_1)$	$\frac{100}{R}(y\,AL)$	$\frac{100}{R}(y_1\,AL_1)$	Closed	Open	Closed	Open
7	Open	Closed	Closed	Open	300	+100	$\frac{300}{R}(x)$	$\frac{400}{R}(x+y_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(x\,I)$	$\frac{300}{R}(y_1\,I)$	Closed	Open	Open	Closed
8	Closed	Closed	Closed	Open	+300	+100	$\frac{300}{R}(y)$	$\frac{200}{R}(y+x_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(y\,AL)$	$\frac{300}{R}(x_1\,L)$	Closed	Open	Closed	Closed
9	Open	Open	Open	Closed											
10	Closed	Open	Open	Closed	+100	−300	$\frac{100}{R}(y)$	$\frac{400}{R}(y+x_1)$	$\frac{300}{R}(x_1)$	$\frac{300}{R}(y\,I)$	$\frac{100}{R}(x_1\,L)$	Open	Closed	Closed	Open
11	Open	Closed	Open	Closed	300	300	$\frac{300}{R}(x)$	0	$\frac{300}{R}(x_1)$	$\frac{300}{R}(x\,AI)$	$\frac{300}{R}(x_1\,AL_1)$	Open	Closed	Open	Closed
12	Closed	Closed	Open	Closed	+300	300	$\frac{300}{R}(y)$	$\frac{600}{R}(y+x_1)$	$\frac{300}{R}(x_1)$	$\frac{300}{R}(y\,AL)$	$\frac{300}{R}(x_1\,AL_1)$	Open	Closed	Closed	Closed
13	Open	Open	Closed	Closed	−100	+300	$\frac{100}{R}(x)$	$\frac{400}{R}(x+y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{100}{R}(y_1\,L)$	Closed	Closed	Open	Open
14	Closed	Open	Closed	Closed	+100	+300	$\frac{100}{R}(y)$	$\frac{200}{R}(y+y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{100}{R}(y_1\,AL_1)$	Closed	Closed	Closed	Open
15	Open	Closed	Closed	Closed	−300	+300	$\frac{300}{R}(x)$	$\frac{600}{R}(x+y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,I)$	$\frac{300}{R}(y_1\,I)$	Closed	Closed	Open	Closed

152. Sixteen different combinations may be formed with the four keys, thus giving sixteen different current combinations. These sixteen possible combinations are tabulated in Table 3.

R in the table refers to the resistance from the point h through the line to the ground G_2 and G_3 at the east station, or from h_1 through the line to the ground G and G_1 at the west station. It is also equal to the resistance from the point h through the artificial-line side at the west station to the ground G_1, or from h_1 through the artificial-line side at the east station to the ground G_3. The resistance of the earth return is in each case neglected.

The letters in parentheses, in columns under "Effective Current," refer to the direction of the current and to the branch carrying the largest current. Thus $\frac{100}{R}$ (x_1 A L_1) means that an effective or excess current of $\frac{100}{R}$ amperes is flowing through the artificial-line coils of the relays at the east station in the direction of the arrow x_1.

Closing the key Tk closes the transmitter T, and closing the key Pk closes the pole changer PC; that is, it causes the positive pole of the battery to be connected to the line, and the negative pole to the ground G. Reversing the battery in this way, so that the point f is shifted from the negative to the positive pole of the battery, will close the distant polar relay.

153. An effective current of the strength $\frac{100}{R}$, which we may call 1 unit, is not strong enough to close the neutral relays when their springs are properly adjusted; and the polar relays are so connected that a current flowing through their artificial-line coils j and j_1 in the direction of the arrows x and x_1, respectively, or through their line coils l and l_1 in the direction of the arrows y and y_1, respectively, will hold the polar relays open. That is, the polar-relay coils are so connected when the apparatus is first set up that

this will be the case. Hence, any current through either or both windings of the polar relay that will magnetize the relay in the same direction as the currents specified above, will hold the polar relay open, and any current that will reverse the direction of this magnetization will close the polar relay. The student must remember this fact.

In order to close the neutral relay, the intensity of the resultant magnetization produced by the current in the two coils must be equivalent to that produced by $\frac{300}{R}$ amperes through one coil only. The direction of the current in the various coils is indicated in the table by the letters x, y, x_{11}, and y_{11}, to be found on the various arrows in the figure. It will be noticed that the arrow x_1 coincides in direction with the arrow y, and y_1 with x. The arrows x_1 and y_1 are not absolutely necessary, but, by using them, the explanations are made clearer.

154. It may be well to add here the fact that some of the current flowing over the line from the east to the west station may go to ground G_1 through the coils i and j and the artificial line, instead of through the pole changer and transmitter circuit to the ground G. This, however, is an advantage rather than a disadvantage, because the direction of this current through the artificial-line coils is always in the proper direction to assist the incoming current through the line coils. Sometimes, when dynamos or batteries of the same electromotive force must be used on both short and long lines, a resistance box is placed in the circuit between the dividing point h and the point f. By this means, too large a current in the relays on the short lines can be prevented by increasing the resistance in the box. As far as the operation of the relays alone is concerned, the use of this resistance is advantageous, as it forces a larger proportion of the incoming line current through the artificial-line coils of the home relays. This resistance is shown in the Jones quadruplex system, an explanation of which will be given later.

155. Fig. 55 is merely a simplified diagram of the quadruplex system. B and B_1 represent the entire group of batteries, or generators, at each end of the line, respectively. PR and PR_1 represent the polarized relays, one at each end of the line; and NR and NR_1, the neutral relays. The crosses at PC and PC_1 represent the pole changers that govern the direction of the current sent to the line; and the crosses at T and T_1, the transmitters that govern the strength of the current. Practically the same notation is used as in Fig. 54, so that in the following explanations either figure may be referred to.

This figure is shown in order that a complete analysis of all the currents in the line and the ground branches of the relays for each of the sixteen possible combinations may be the more easily made. The formation of these different combinations is explained in the following articles.

156. First Combination.—In the first combination, No. 1 in the table, all four keys are open and, consequently, the negative poles of the short-end batteries, having an electromotive force of 100 volts, are connected to the points h and h_1. Then we have -100 in columns 6 and 7. Since these two electromotive forces oppose each other, there will be no current in the line L or in the line coils o, l, o_1, and l_1 of the four relays; hence, we have 0 (zero) in column 9. There is current, however, of an intensity of $\frac{100}{R}$, in the direction of the arrows x and x_1 in the artificial-line coils of all relays. The intensity of this current is not great enough to close the neutral relays, and its direction is such as to hold the polar relays open. Hence, we have $\frac{100}{R}$ (x) for column 8 and $\frac{100}{R}$ (x_1) for column 10. Since there is no current in the line coils of the four relays, as indicated by 0 in column 9, it is evident that the effective current has a strength of $\frac{100}{R}$ and flows in the direction of the arrow x in

the artificial-line circuit $A\ L$ at the west end, and in the direction of the arrow x_1 in the artificial-line circuit $A\ L_1$ at the east end. This is indicated by $\frac{100}{R}$ $(x\ A\ L)$ and

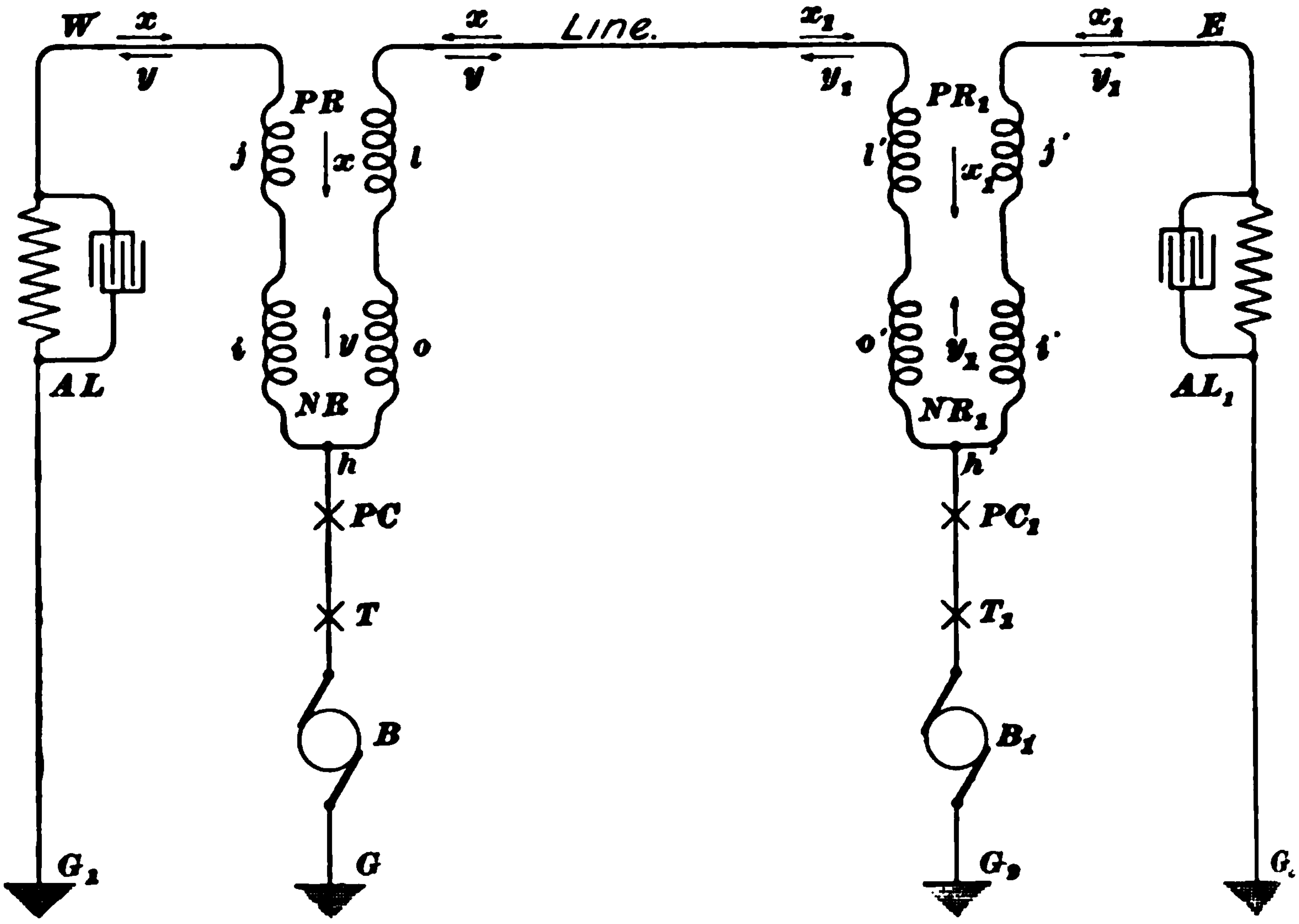


FIG. 55.

$\frac{100}{R}$ $(x_1\ A\ L_1)$ in columns 11 and 12, respectively. All the relays will be open, as indicated, in columns 13, 14, 15, and 16.

157. Second Combination.—*Pk* is the only key closed in this combination. Closing the key *Pk* reverses the short-end battery B_1 in Fig. 54, causing the potential at *h* to be $+100$. Consequently, B_1 and B_2 are now in series, giving $\frac{200}{R}$ (y) in the line coils *o* and *l*, and $\frac{100}{R}$ (y) in the artificial-line coils *i* and *j*. The $\frac{200}{R}$ (y) in *o* and the $\frac{100}{R}$ (y) in *i* will give an effective current of $\frac{100}{R}$ (y) in *o* because the current flows from *h* through the two coils *o* and *i* in opposite directions around the iron core; hence, the $\frac{200}{R}$ (y) in *o*

neutralizes $\frac{100}{R}$ (y) in i and still has left $\frac{100}{R}$ (y) with which to magnetize the neutral relay NR. This current is too weak, however, to close this relay. Hence, closing the pole-changer key Pk does not affect the neutral relay NR.

As in the case of the neutral relay NR, the current $\frac{200}{R}$ (y) in l and the current $\frac{100}{R}$ (y) in j flow in opposite directions around the cores of the polar relay, giving an effective current equivalent to $\frac{100}{R}$ (y) in l alone, which will, on account of the direction in which it flows, continue to hold the polar relay PR open. Or, we may consider that the current of $\frac{100}{R}$ (y) now flowing in the coil j tends to close the polar relay, but that the current $\frac{200}{R}$ (y) in the coil l tends to keep it open, and since $\frac{200}{R}$ is twice $\frac{100}{R}$, the resultant magnetism, which is due to $\frac{100}{R}$ (y) in the coil l, will hold PR open. Hence, closing the key Pk does not affect either of the home relays NR or PR.

There is a current of $\frac{200}{R}$ (x_1) in l_1, and $\frac{100}{R}$ (x_1) in j_1. The current in j_1 is the same in strength and direction as before and tends to hold the polar relay open, but $\frac{200}{R}$ (x_1) in l_1 tends to close the relay, hence the resultant magnetism which is due to $\frac{100}{R}$ (x_1) in l_1 will close PR_1, as stated in column 15. The resultant of $\frac{200}{R}$ (x_1) in o_1 and $\frac{100}{R}$ (x_1) in i_1, is $\frac{100}{R}$ (x_1) in o_1. This is not sufficient current to close NR_1, hence it remains open. Therefore, when Pk alone is closed, the only relay that responds is the polar relay PR_1 at the distant end.

158. Third Combination.—The only key closed in this combination is Tk. Closing the key Tk connects the long end of the battery, that is, both B and B_1 in series, to the point h at the west station; hence, we have -300 volts at h and -100 at h_1. The current in the line circuit will be $\frac{200}{R}$ $(x y_1)$. The current in i and j will be $\frac{300}{R}$ (x); hence, the effective current that is due to $\frac{200}{R}$ (x) in l and $\frac{300}{R}$ (x) in j will be $\frac{100}{R}$ (x) in j. The resultant magnetization will hold the polar relay PR open.

The resultant magnetization of the neutral relay NR is due to $\frac{200}{R}$ (x) in o and $\frac{300}{R}$ (x) in i; this is equivalent, as in the polar relay PR, to the magnetization produced by a current of $\frac{100}{R}$ (x) in the coil i. This current is not strong enough to close the neutral relay NR, hence it remains open.

Since the full battery, 300 volts, at the west station opposes the short-end battery of 100 volts at the east station, the effective electromotive force in the line circuit, that is, the difference of potential between the points h and h_1, will be 200 volts in the direction of the arrows x and y_1. Hence, the current in the line coils l_1 and o_1 will be $\frac{200}{R}$ (y_1). The difference of potential between the point h_1 and the ground G_2 is 100 volts, due to the short-end battery B_3. This difference of potential tends to send a current of $\frac{100}{R}$ amperes through the artificial-line circuit $A L_1$ in the direction of the arrow x_1. Hence, the current in the artificial-line coils j_1 and i_1 is $\frac{100}{R}$ (x_1). Now the currents in the line and artificial-line coils of the east relays circulate around the iron cores in such a direction that they help each other in magnetizing the relays; hence, the

resultant magnetization due to a current of $\frac{200}{R}$ (y_1) in the line coils and a current of $\frac{100}{R}$ (x_1) in the artificial-line coils is equivalent to that produced by a current of $\frac{300}{R}$ (x_1) in the artificial-line coils j_1 and i_1. The direction of this current in the coil j_1 is such that the polar relay PR_1 remains open, but $\frac{300}{R}$ in i_1 is strong enough to close the neutral relay NR_1. Hence, when the key Tk that controls the number of cells connected to the circuit at the west station is closed, the only relay closed is the neutral relay NR_1 at the distant east station.

159. Fourth Combination.—In this combination, the two keys Tk and Pk are closed. Hence, the positive pole of the whole battery at the west station is connected to h, giving that point a potential of $+300$ volts, h_1 remaining at -100, as in all preceding combinations. The current in the line and in the coils o, l, l_1, and o_1 will be $\frac{400}{R}$ $(y\,x_1)$, and the current in the artificial line and in the coils i and j will be $\frac{300}{R}$ (y). Hence, the effective current, due to the difference between $\frac{400}{R}$ (y) in the line and $\frac{300}{R}$ (y) in the artificial line, will be $\frac{100}{R}$ (y) in the line coils o and l. Now, a current of $\frac{100}{R}$ (y) in the coil l is equivalent in its magnetizing effect, both in direction and intensity, to a current of $\frac{100}{R}$ (x) in the artificial-line coil j, but a current in the artificial-line coil j in the direction of the arrow x will hold the polar relay open. Therefore, the polar relay PR is held open by the effective current $\frac{100}{R}$ $(y\,L)$.

Furthermore, this effective current $\frac{100}{R}$ $(y L)$ through the coil o is not strong enough to close the neutral relay NR. The current in the coils l_1 and o_1 is $\frac{400}{R}$ (x_1), and in j_1 and i_1 the current is $\frac{100}{R}$ (x_1). Hence, the resultant current $\frac{300}{R}$ (x_1) is not only strong enough to close NR_1, but it is also in the right direction to close the polar relay PR_1. Hence, the closing of the two western keys closes only the two eastern relays.

160. Similarly, the currents in the line and artificial-line circuits and the relays affected by the other various positions of the four keys may be worked out. The table is complete except for the ninth combination, which is left blank in order that the student may fill in these spaces for himself, and thereby acquire a better knowledge of the system.

161. Either side of a quadruplex can be used as a duplex; the polar side as a polar duplex, or the neutral side as a Stearns duplex. Duplex sets were excluded from the main office of the Postal Telegraph Company in Philadelphia, which was completed in September, 1900, and only single and quadruplex sets were installed. By this arrangement a second side is always available, when required on a circuit that is at the time being worked duplex.

QUADRUPLEX TERMS.

162. It will be well to give here some of the terms commonly used in quadruplex telegraphy. The battery B_1, Fig. 54, is called the *short end*, and B the *long end;* sometimes, however, the term *long end* means the whole battery, that is, both B and B_1. The point q, Fig. 54, is termed the *tap*, and the branch $q\,v$, the *tap wire*. That portion of the

quadruplex that is operated by opening and closing the transmitter key is called the *neutral*, *common*, or *No. 2 side*; and that portion that is operated by the pole-changer key is called the *polar* or *No. 1 side* of the system. These terms are also applied to the relays; that is, the relay that is operated by the increase and decrease in the strength of the current is called the *neutral*, *common*, or *No. 2 relay*; and the relay that is operated by a change in the direction of the current through it is called the *polar* or *No. 1 relay*. *Excess current* means the excess of current in one winding of a relay over the current in the other winding of the same relay. The coil, lettered *Gc* in most of the diagrams, that is included in the circuit in place of the transmitting apparatus and source of current at one end when the system is being balanced, is called the *ground coil*. It is used to replace whatever resistance there may be in the transmitting apparatus when the latter is cut out of the circuit. By this means the resistance from the line through the office apparatus to the ground is kept the same whether the transmitting apparatus is cut in or out.

The pull that can be allowed on the armature of either relay without interfering with the proper working of the system is called the *margin*. The margin is sometimes defined as the pull or number of turns (either up or down) that may be given to the retractile spring of the neutral relay without interfering with the incoming signals on that instrument. The margin on the neutral relay, which we prefer to define as the difference in pull on the armature of the neutral relay due to the difference between the strength of the current produced respectively by the short end and long end of the distant battery, that is, the difference in pull produced in the open and closed positions of the distant transmitter, may be increased by increasing the ratio of the strength of the current in these two positions of the transmitter. This may be done by increasing the electromotive force of the long end of the battery, or by decreasing the electromotive force of the short end of the battery; or by properly altering, in some quadruplex systems, certain

resistances included in the circuit. Evidently, the margin on the polar relay is the pull due to the short end of the battery, for the reversal of the short end gives the smallest force that must move the armature. Hence, to increase the margin on the polar relay, the electromotive force of the short end of the battery must be increased or the resistance of the circuit must be decreased.

The coils Cr and Cr_1, Fig. 56, which are in series with the condensers in the artificial line, are often called the *retarding* or *retardation coils*, because they retard the charge and discharge of the condensers.

163. The principles of the quadruplex telegraph system having been fully explained, it now remains to show several improvements that are used in the practical operation of the system, and, also, the manner in which the apparatus is arranged when dynamos are used in place of primary batteries. One of the difficulties to be overcome in quadruplex systems is to prevent the armature of the home neutral relay from being released when the distant pole changer passes through its middle position and reverses the direction of the current. This change in the direction of the current reverses the magnetism of the neutral relay, and, hence, there is an interval, although very small, during which the neutral relay, in passing from one direction of magnetization to the other, possesses no magnetism.

164. Advantage of Repeating Sounder.—To diminish the evil effect due to the reversal of the distant pole changer when the distant transmitter is closed, Edison inserted a repeating sounder between the relay and the reading sounder, connecting the circuit of the magnet of the repeating sounder to the back stop of the neutral relay and the circuit of the reading sounder to the back stop of the repeating sounder. This arrangement has already been explained in connection with the diplex telegraph system.

If the reversal in the magnetism of the neutral relay should occur while the relay is closed, although it might be of sufficient duration to break the front contact, still no click

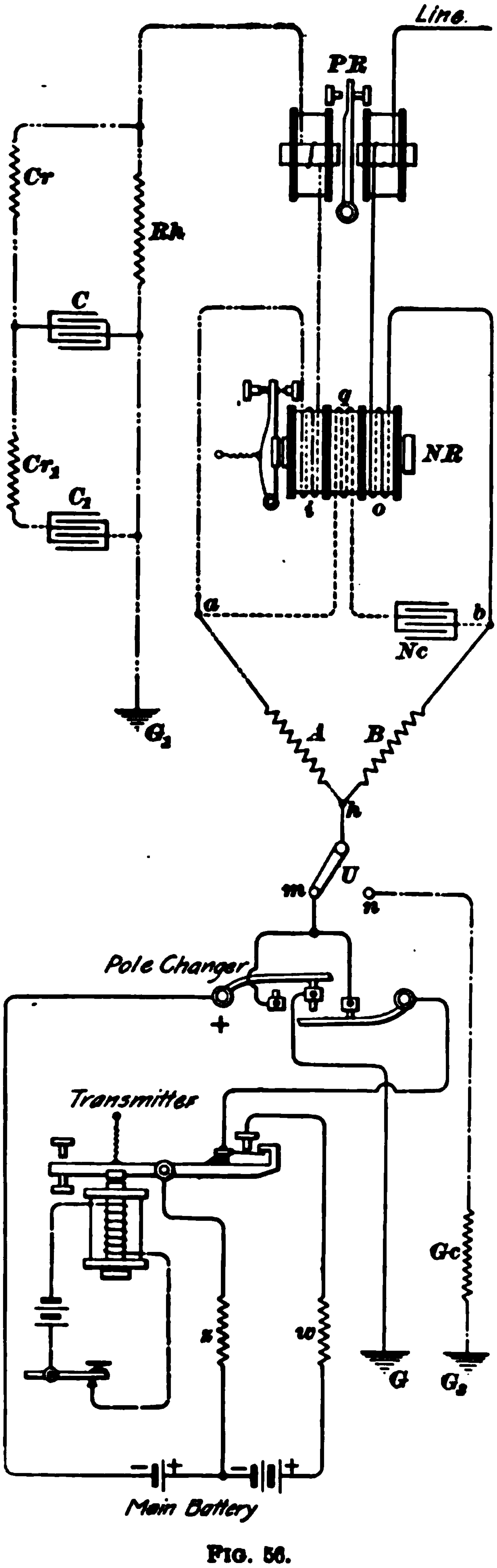


FIG. 56.

will ordinarily be heard on the receiving sounder, because the lever does not have sufficient time to cross the gap and touch the back stop, and thereby close the circuit containing the repeating sounder. It is evident, therefore, that the relay points should not be placed too near each other, nor the fact overlooked that there is such a thing as a proper adjustment of those points.

165. Smith Extra Coil and Condenser Device.—To still further reduce the evil effect due to the interval of no magnetism in the neutral relay when it should remain closed, an arrangement, shown in Fig. 56, is used by the Western Union Telegraph Company. It was introduced by Mr. Gerritt Smith in 1884 and is known as the **Gerritt Smith device.**

In this figure it will be noticed that the neutral relay *NR* has three distinct windings on each core. (In this figure only one core is shown.) In addition to the usual line

and artificial-line coils *o* and *i*, respectively, there is an extra coil *q* between the other two coils. This coil *q* is connected in series with a condenser *Nc*, and across the line and artificial-line circuits, from *a* to *b*, as shown. There are also two coils *A* and *B* of 300 ohms resistance each. The object of these two equal resistances *A* and *B*, the condenser *Nc*, and the extra coil *q* is to tide the neutral relay over the period of reversal. This coil *q* is wound and connected in such a direction that it tends to help the other coils close the relay.

When the distant pole changer short-circuits its battery while the home neutral relay is closed on account of the distant transmitter being closed, the condenser discharges through this coil *q* in such a direction as to tend to hold the relay closed. The current that charges back through the coil *q* when the distant pole changer again restores the line current, circulates around the relay coils in a direction opposite to that of the current that has just ceased, and tends to hold the armatures to the cores until the reverse current coming over the line from the distant end reaches its full strength. This reverse current charges the condenser in an opposite direction, causing the charging current to flow in the same direction through the extra coil as did the preceding discharging current. Hence, the charging current, which has a maximum strength when the distant pole changer first connects the opposite polarity to the line and decreases in strength as the line current approaches its steady maximum value, also tends to hold the relay closed. These charging and discharging currents are at a maximum when the line current passes through zero, and since both the discharging and charging currents passing through the extra coil are in the same direction and tend to magnetize the relay in the same direction as the reversed line current, it is evident that the period of no magnetism is considerably reduced.

166. If there was no resistance *A* and *B* in the circuit *a–h–b*, the terminals *a* and *b* of the condenser and extra

coil would never have any difference of potential; hence, there would be no charging or discharging current to flow through the extra coil. The difference of potential between a and b will depend on the products of the currents and the resistances in the circuits a–h and b–h. In order not to destroy the balance between the line and artificial-line circuits, A and B must be equal in resistance.

It is necessary to so arrange the connections of the coil q that the charging currents from the line and condenser will circulate around the ordinary and extra coils of the relay in the same direction. Long theoretical explanations could be given to show that this coil q and the condenser will always tend to tide the relay over the period of the reversal when the neutral relay is closed. However, the fact that practical experience has shown this to be the case is sufficient reason for this arrangement.

167. Three-Coil Neutral Relay.—The **three-coil neutral relay,** as it is called, is shown in Fig. 57. The iron cores are extremely short, and no more iron is used in the relay than is really necessary; the moving parts are made

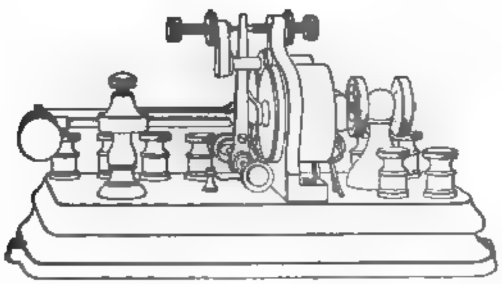


FIG. 57.

as light as possible, so that both the magnetic and the mechanical inertia are reduced to a minimum. As a result of this construction the relay is very quick-acting.

The cores in the neutral relay used by the Western Union Company have a diameter of $\frac{1}{2}$ inch and a length of $1\frac{3}{16}$ inches. The armature lever is $2\frac{3}{4}$ inches long, while the coils are $1\frac{1}{16}$ inches in length and $1\frac{1}{2}$ inches in diameter.

168. The way in which the coils are wound is shown in Fig. 58. In all quadruplex relays it is very necessary that the coils forming the two halves of the differential winding shall have the same number of turns and the same resistance. In order that this will be the case, the first coil that is wound on the core *a* is connected in series with the second coil on the core *b*; these two coils, so connected, form one half of the differential winding. The other half of the differential winding consists of the first coil that is wound on *b* connected in series with the second coil on *a*. The third coil that is wound on *a* is connected in series with a third coil wound on *b*, the two together forming the extra coil

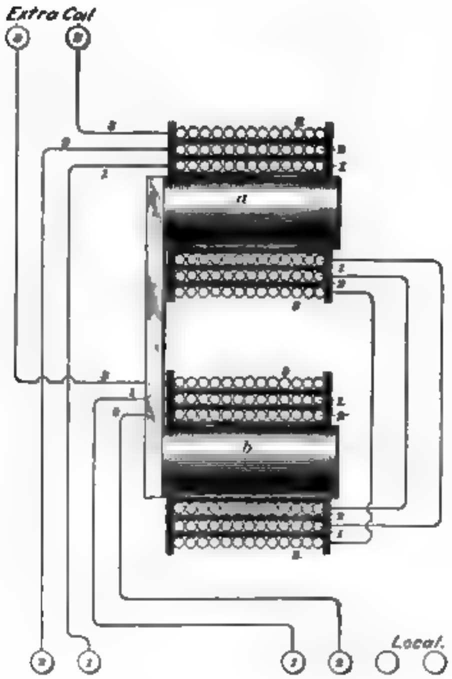


FIG. 58.

The binding posts marked *3* form the terminals of the extra coil; the binding posts marked *2*, the terminals of the artificial-line coil; and the binding posts marked *1*, the terminals of the line coils.

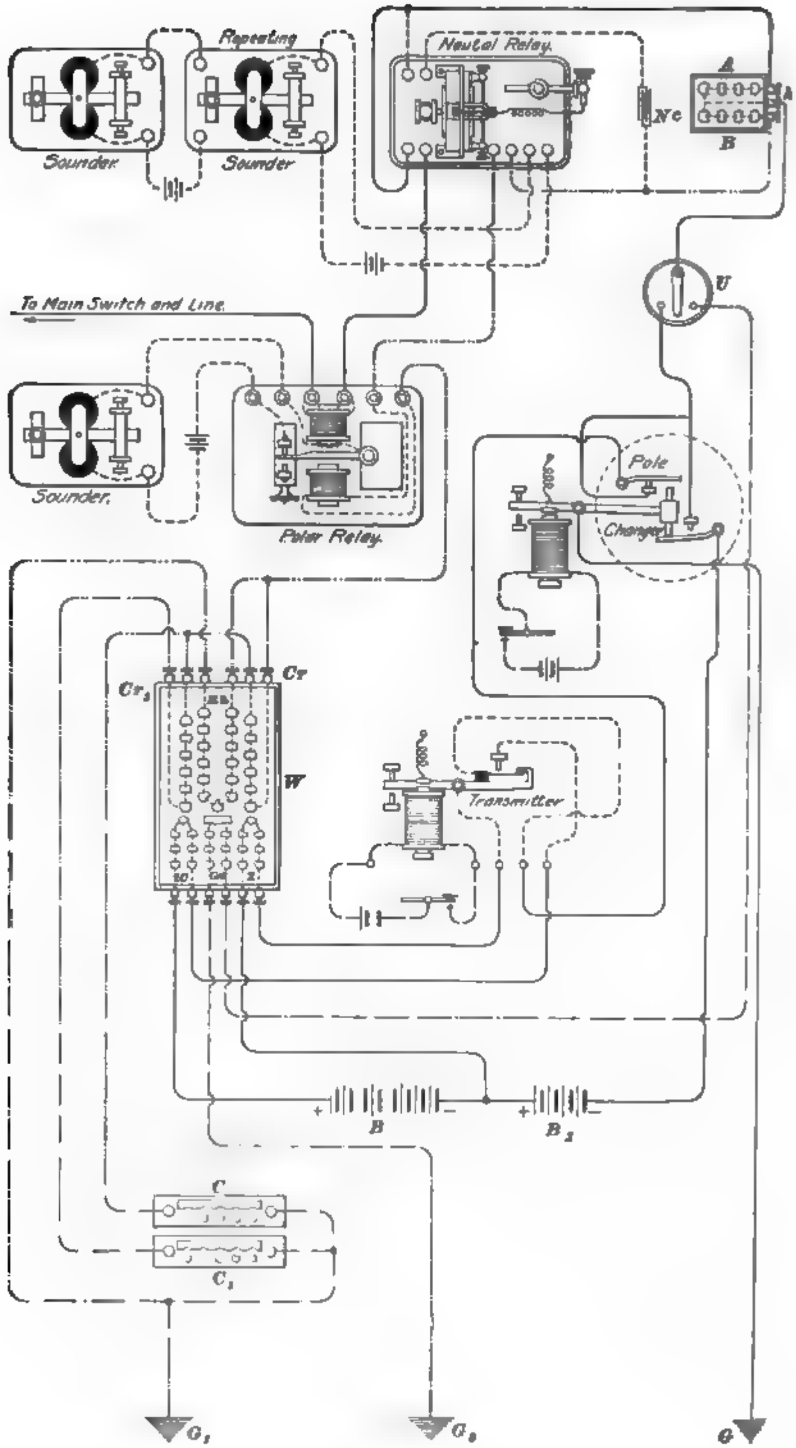
Each coil on each core contains 1,800 turns of about No. 36 B. W. G. silk-covered wire. Each half of the differential winding has a resistance of about 225 ohms, while the extra coil has a resistance of from 400 to 450 ohms. The third coil has a higher resistance than the other two because it is wound on the outside, and, hence, requires more wire for the same number of turns. For long-line circuits,

the line and artificial-line coils are sometimes wound to have a resistance of 400 ohms each.

169. The manner in which resistances and condensers are connected together to form the artificial line in the Western Union quadruplex system is shown in Fig. 56. *Rh* is the main resistance that is adjusted to equal the resistance in the line circuit to the ground at the distant station. The condenser *C* is so connected around this resistance that its charging and discharging current must flow through the resistance *Cr*. The condenser C_1 is so connected that its charging and discharging current must flow through both resistances *Cr* and Cr_1. The resistances *Rh*, *Cr*, and Cr_1, and the condensers *C* and C_1 are all adjustable, so that the resistance and capacity of the artificial line can readily be adjusted to equal that of the line circuit.

170. Ground Coil.—*U* is a switch that ordinarily rests on contact button *m* when the system is in operation, but the arm is turned to *n* when it is necessary to balance the set. Turning the arm of the switch *U* to *n* cuts out the main battery, transmitter, and pole changer, and grounds the receiving apparatus directly through the so-called **ground coil** *Gc*. The resistance of *Gc* is made equal to the resistance of the circuit from *h* through the main battery to the ground at *G*.

171. It frequently happens when the weather is very stormy and wet that it is impractical to obtain the margin necessary for the successful working of the neutral side of the quadruplex. In such a case it is better to close the neutral side and not attempt to use it, but to work the set as a polar duplex simply. When this is done, it is frequently necessary, in order not to have an excessive current, to include a resistance *w*, Fig. 56, in series with the whole battery. The increase in the strength of the current from the battery is due to leakage from the line through wet trees, insulators, and posts. Moreover, when only the polar side is in operation, less current is required than would be



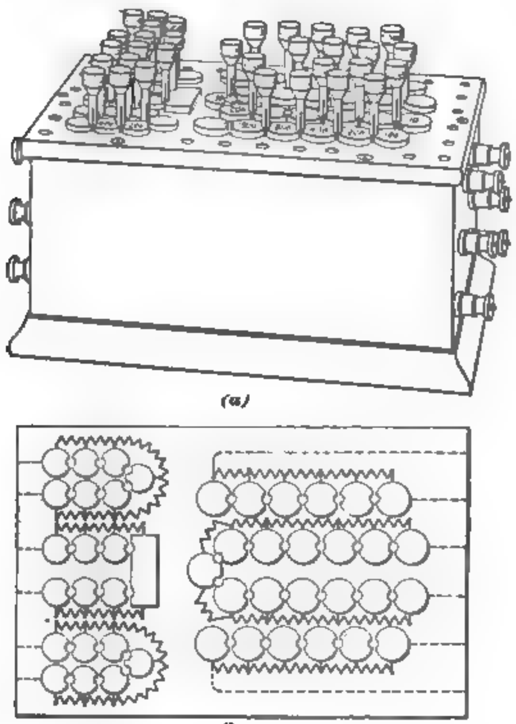
Repeating
Sounder
Sounder
Neutal Relay.
Nc
A
B
U
To Main Switch and Line.
Sounder.
Polar Relay.
Pole
Changer
Transmitter
W
B
B_2
C
C_1
G_1
G_2
G

FIG. 59.

given by the whole quadruplex battery, but preferably more than would be given by the short-end battery alone. When the weather clears and the system can be again worked as a quadruplex, this resistance w is cut out.

WESTERN UNION BATTERY QUADRUPLEX.

172. Fig. 59 shows the practical arrangement of the **Western Union quadruplex system,** in which gravity batteries are employed for both main and local circuits.



(a)

(b)

FIG. 60.

The various condensers and instruments are lettered exactly as in Fig. 56. In connection with the neutral relay a repeating sounder, controlling an ordinary sounder, is used

for the reason already explained. The pole changer is of the clock-face type, and the transmitter is one of the ordinary continuity-preserving kind. The box *IV* contains all the various resistance coils except the two *A* and *B* that are used in connection with the extra coil on the neutral relay. The resistance *Gc* is made equal to the resistance of the battery circuit; that is, to the internal resistance of the whole battery *B* and B_1. Thus, when the switch *U* is turned to the right, the point *h* to which the neutral and polar relays are connected is joined directly to the ground G_3 through the resistance *Gc*, so that the resistance offered to the incoming current is the same as in the working condition of the apparatus.

173. Fig. 60 (*a*) shows the general appearance of the box *IV*, which contains six separate adjustable resistances, there being six binding posts on each end of the box; the resistance of these coils is adjusted by means of numerous pegs. In Fig. 60 (*b*) is shown, in a clearer manner, the six separate resistances just mentioned. The wave lines represent the resistances, usually non-inductively wound coils of German-silver wire, that are contained in the box and connected to the insulated brass pieces on the top of the box as indicated.

DYNAMO QUADRUPLEX SYSTEMS.

174. A different arrangement to that which has already been explained is necessary when dynamos are used in the quadruplex systems in the place of primary batteries. For the sake of economy, one dynamo supplies current for all circuits requiring about the same voltage, in which case it is impossible to reverse the line and earth connections of the dynamo without also reversing the polarity for all other line circuits that are supplied by that same dynamo. Hence, in duplex and quadruplex systems, one dynamo is used to supply negative current, and another to supply positive current. The machines themselves are never reversed; the

line connection is merely shifted from one machine to the other. Furthermore, it is sometimes desirable to make one dynamo supply both the long-end and short-end currents of one polarity, and another dynamo to supply both the long-end and short-end currents of the opposite polarity. It is a well-known fact that we can increase and decrease the current in a circuit by increasing or decreasing the resistance in series with a dynamo that generates a constant electromotive force.

PRINCIPLE OF WESTERN UNION DYNAMO QUADRUPLEX.

175. In applying dynamos to quadruplex telegraphy it is desirable to retain, as far as possible, the same apparatus used with gravity cells. With the exception of the extra resistances that are required, in the Western Union quadruplex, the same apparatus has not only been retained but it has, if anything, been simplified. In Fig. 61 is shown the theoretical arrangement of instruments when dynamos are used to supply the current for this quadruplex system.

The pole changer and the dynamos D and D' are arranged in the same manner as in the polar duplex, and the continuity-preserving transmitter is the same as the one used in several systems that have already been described. It is necessary in a quadruplex system, not only to be able to reverse the current and to vary the strength of the current in the ratio of 1 to 3 or 1 to 4, but it is also necessary to keep the resistance of the circuit at each terminal station as constant as possible. It would not do to directly insert or remove a resistance in such a manner as to appreciably alter the resistance of the whole system.

176. The arrangement of resistances shown in this figure was devised by Mr. S. D. Field for the Western Union Telegraph Company. In this figure, two resistance coils, one of 1,200 ohms and another of 900 ohms, called the *added resistance* and *leak coil*, respectively, are so arranged in connection with the pole changer and the transmitter that the

resistance of the circuit remains practically constant in all possible positions of these two instruments. The lever f of the pole changer is connected to a point a where the circuit

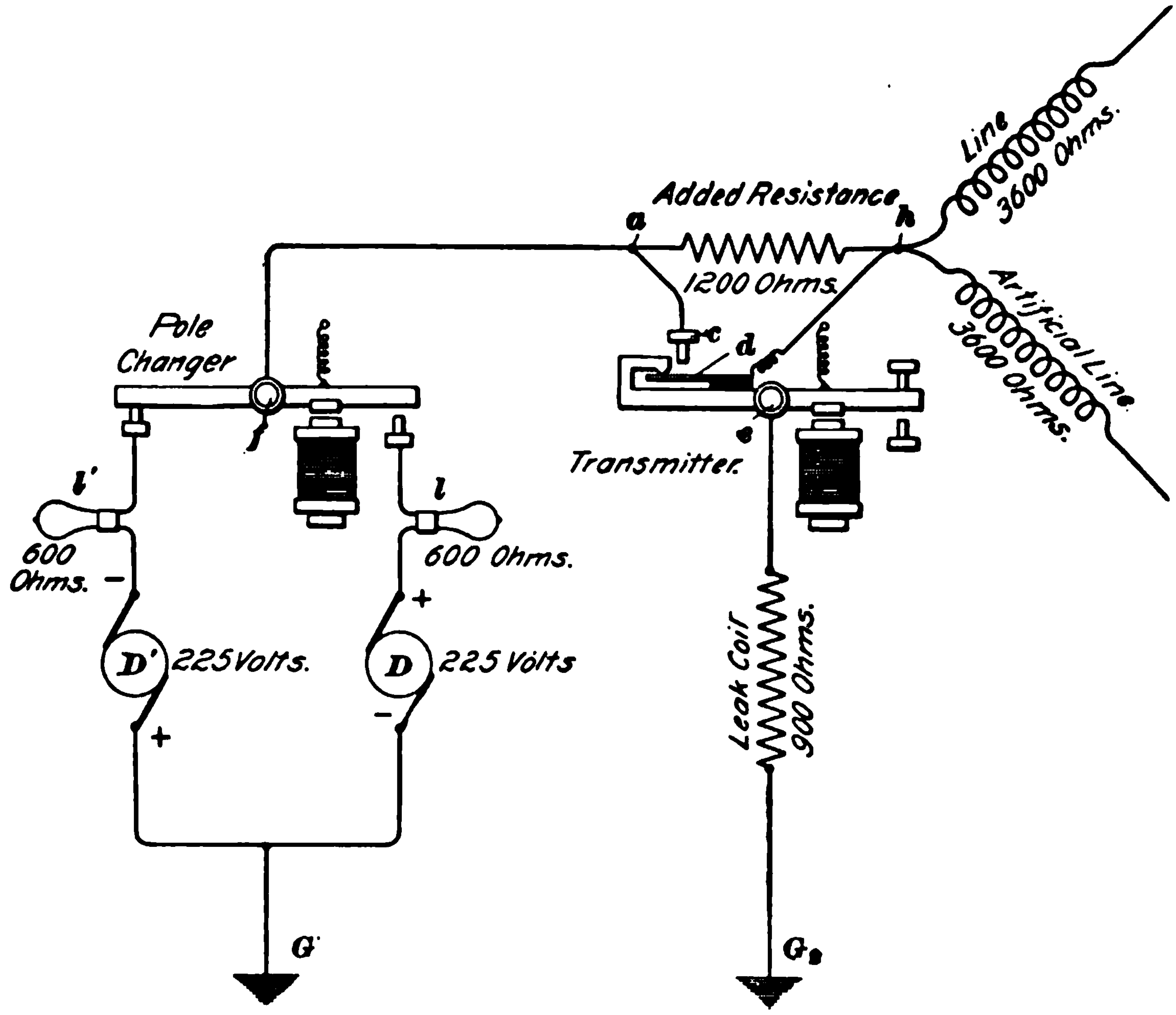


FIG. 61.

branches, one branch being directly connected to the stop c on the transmitter, and the other branch through the added resistance of 1,200 ohms to the point h.

The line and artificial-line circuits come together at the point h, which is also connected directly to the tongue d of the transmitter. The 900-ohm leak coil is connected between the lever e of the transmitter and the ground G_2.

177. Let us suppose that the line circuit, which includes the line coils of the neutral and polar relays and the apparatus in the line circuit at the distant station, has a resistance of 3,600 ohms, then the artificial-line circuit will have the same resistance. In series with each dynamo is a lamp of

600 ohms, which is necessary to protect the dynamos from injury due to an accidental short circuit.

178. Resistance of Circuit Is Constant.—The resistance of the circuit from h to the ground through the transmitter and pole changer at the home office to incoming currents is constant whether the transmitter is open or closed. With the transmitter open, the added resistance, 1,200 ohms, is in series with the 600-ohm lamp l or l', making 1,800 ohms in this path. This 1,800 ohms, however, is in parallel with the 900-ohm leak coil, and, hence, the combined resistance of these two paths from h to the ground is

$$\frac{900 \times 1,800}{900 + 1,800} = 600 \text{ ohms.}$$

When the transmitter is closed, the *added resistance is short-circuited*, because the tongue d touches the contact stop c; and the *leak coil is on open circuit*, because the tongue d no longer touches the hook of the lever e. Hence, the only resistance between the point h and the ground through the transmitter and pole changer is the 600-ohm lamp in the dynamo circuit.

Therefore, the resistance from h to the ground through the transmitter and pole changer is the same, 600 ohms, in both positions of the transmitter. Evidently, the resistance is also the same in the two positions of the pole changer, because there is a similar 600-ohm lamp in series with each dynamo. Moreover, the resistance of the artificial line remains the same, namely, 3,600 ohms; hence, the combined resistance to incoming currents of all possible paths from h to the ground at the *home station* is always

$$\frac{3,600 \times 600}{3,600 + 600} = 514 \text{ ohms.}$$

Therefore, the incoming line current has a path of the same resistance from h to the ground in the open and closed positions of both the transmitter and pole changer. Since the same is also true at the distant end, it follows that the

resistance of the circuit is the same for all sixteen combinations of the four keys, as long as the resistance of the line circuit remains constant.

179. Furthermore, it can be shown that the total current supplied by either dynamo to one quadruplex circuit arranged in this manner is the same in both the open and closed positions of the transmitter. This remark does not strictly apply to intermediate positions of the two pole changers (one at each end). In the intermediate position of the pole changer, both dynamos, with their 600-ohm lamps, are on open circuit, but the time during which this is the case is extremely short when the pole changer is properly adjusted. It probably has some effect on the distant neutral relay, due to the fact that the line retards the arrival of the reversed current; and the neutral relay, although exceedingly quick in magnetizing and demagnetizing, has some magnetic inertia, though the amount may be very small, that must be overcome; hence, some time is required to reverse its magnetism. The momentary absence of the current does not cause any trouble in the polar relay, for, as has already been explained, the tongue of the polar relay will remain on whichever side it happens to be at the instant when the current ceases.

When the transmitter is open, the resistance from G through either dynamo circuit to the point h is 1,800 ohms. From the point h to the ground through both the line and the artificial-line circuits the resistance is 1,800 ohms, since the line and artificial-line circuits are in parallel with each other. This 1,800 ohms is in parallel with the 900-ohm leak coil; hence, the total resistance from h to the ground through the line, artificial line, and leak coil is

$$\frac{1{,}800 \times 900}{1{,}800 + 900} = 600 \text{ ohms.}$$

This resistance is in series with the 1,800 ohms in the dynamo circuit (1,200 in the added resistance and 600 in the lamp); hence, the total resistance of the circuit to which the dynamo

supplies current, in the open position of the transmitter, is 1,800 + 600 = 2,400 ohms.

180. When the transmitter is closed, the added resistance is short-circuited and the leak coil is on open circuit. Then the resistance from the ground G through either dynamo to the point h is 600 ohms, and the path from h to the ground consists only of the line and the artificial-line circuits, which have a combined resistance of 1,800 ohms. Thus the total resistance of the circuit to which the dynamo supplies current in the closed position of the transmitter is 600 + 1,800 = 2,400 ohms, the same as in the open position of the transmitter. Therefore, since the resistance remains the same, the current supplied by the dynamo will remain the same.

The amount of current that will flow into the line in the two positions of the home transmitter may be calculated as follows.

181. Transmitter Open.—It was shown in the last paragraph of Art. **179** that the total resistance of the circuit to which either dynamo supplies current when the transmitter is open is 2,400 ohms; hence, if the dynamo generates an electromotive force of 300 volts, there will be flowing between the ground G and the point h a current of

$$\frac{300}{2,400} = .125 \text{ ampere, or } 125 \text{ milliamperes.}$$

This current divides at the point h and flows through three paths. The same quantity evidently flows through the artificial-line circuit as flows through the line circuit, because the two circuits are exactly equal in resistance; hence, by calculating the total current that flows through these two circuits, the strength of the current that flows in the line circuit may be found by dividing the result found by 2. The joint resistance of the line and the artificial-line circuit, which are in parallel, will evidently be one-half of 3,600 ohms, or 1,800 ohms. This 1,800 ohms is in parallel with the leak coil of 900 ohms. The total current will divide

inversely in proportion to the resistance in these two circuits, and the sum of the currents in the line and artificial-line circuits will be to the total current supplied by the dynamo as the joint resistance of the three paths, 600 ohms $\left(= \frac{1,800 \times 900}{1,800 + 900}\right)$, is to the joint resistance of the line and artificial-line circuits, 1,800 ohms. Consequently, the sum of the two currents that will flow in the line and in the artificial-line circuits will be

$$\frac{600}{1,800} \times 125 = 41.6 \text{ milliamperes,}$$

and the current in the line will be one-half of 41.6, or 20.8 milliamperes.

182. Transmitter Closed.—When the transmitter is closed, the 1,200-ohm added resistance is short-circuited through the contact stop *c* and the tongue *d* of the transmitter, Fig. 61, and the 900-ohm leak coil is cut out of the circuit. With the transmitter in this position, the total resistance of the circuit will be 600 ohms + 1,800 ohms = 2,400, as before, and the total current is also the same. The total current will be 125 milliamperes, and one-half of this, or 62.5 milliamperes, will flow through the line.

183. Ratio of the Two Currents.—When the transmitter was open, the current in the line was 20.8 milliamperes; when closed, the current was 62.5 milliamperes. From this fact, it is evident that closing the transmitter increases the current *in the line* from 20.8 milliamperes to 62.5 milliamperes; that is, in the ratio of about 1 to 3. Nevertheless, the resistance of the home circuit to incoming currents and the total current remains the same in both positions of the transmitter.

It is frequently desirable to have the ratio of the current increase 1 to 4 instead of 1 to 3. In order to accomplish this, it is only necessary to increase the 1,200 ohms in the added resistance to 1,800 ohms, and to decrease the 900 ohms in the leak coil to 800 ohms. It can be shown in the same manner

as above that the ratio of the strength of the current in the two positions of the transmitter will now be as 1 to 4.

184. Added Resistance and Leak Box.—In order to readily accomplish this change in the added resistance and leak coil, the resistance box shown in Fig. 62 is used. Between the binding posts *a* and *b* two coils are joined in series, one of which has a resistance of 600 ohms and the other a resistance of 1,200 ohms; and between the binding posts *c* and *d*, two coils are joined in series, one of which has a resistance of 100 ohms and the other a resistance of 800 ohms. The resistance between the binding posts *a* and *b* will be 1,800 ohms when there is no plug in the hole at *e*. When, however, a plug is put in the hole at *e*, the resistance between *a* and *b* is only 1,200 ohms, because the 600-ohm coil is short-circuited. When there is no plug in the hole at *f*, the resistance between *c* and *d* is 900 ohms, and when there is a plug in the hole at *f*, the resistance between *c* and *d* is only 800 ohms. Hence, it is evident that with one plug in the hole at *e* we have an added resistance of 1,200 ohms and a leak coil of 900 ohms. By shifting this plug from *e* to *f*, the added resistance is 1,800 ohms and the leak coil 800 ohms; hence, it is a very simple matter to change the ratio of the current from 1 to 3 to 1 to 4.

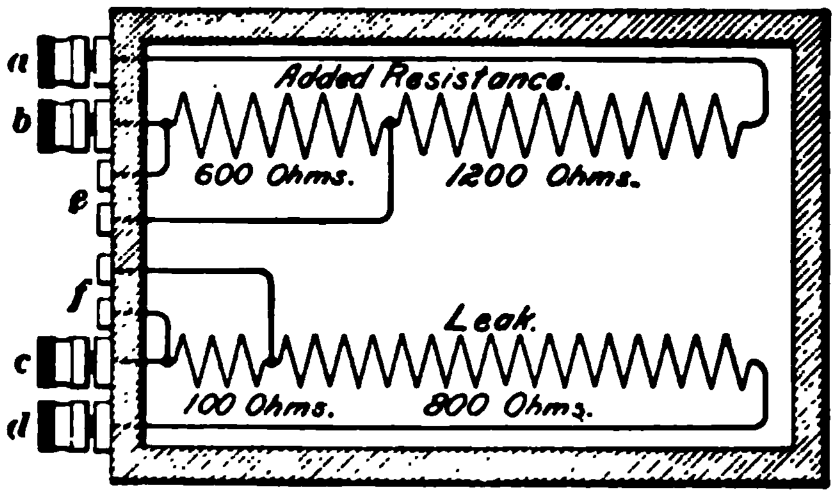
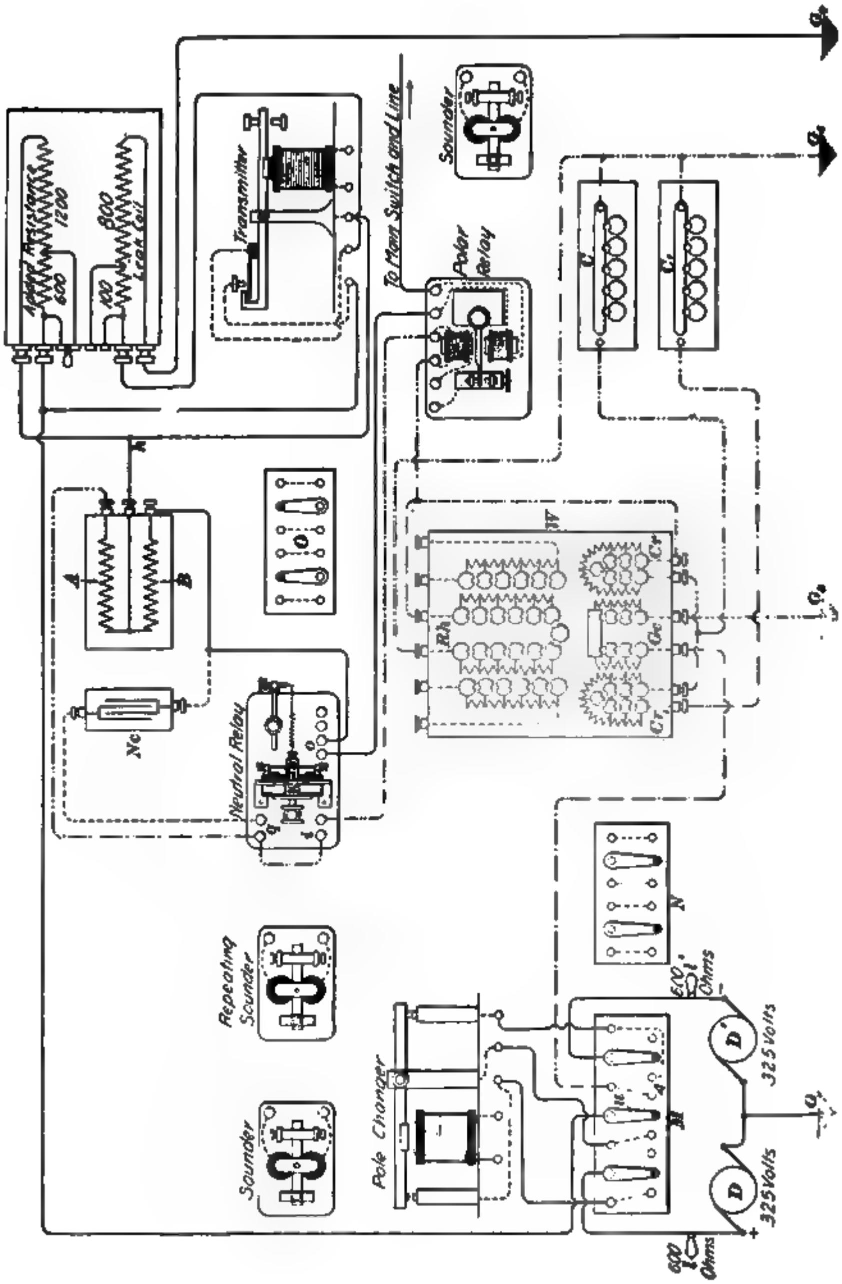


FIG. 62.

185. Western Union Dynamo Quadruplex.—Fig. 63 is a diagram of the Western Union quadruplex, showing the connections of the main-line and artificial-line circuits when dynamos are employed. The local circuits for the sounders, transmitter, and pole changer are shown in Figs. 67 and 68. The apparatus and connections in Fig. 63 are lettered, as nearly as possible, as in the preceding figures.


Added Resistance
Leak Coil
Transmitter
To Main Switch and Line
Sounder
Polar Relay
Neutral Relay
Repeating Sounder
Sounder
Pole Changer
325 Volts
325 Volts

The three arms of the switch *M* are all turned to the left when the system is in working order. The arm *u* of the switch *M* is turned so as to rest on the right-hand button *4* when the set is being balanced. This disconnects the two dynamos *D* and *D'* and the pole changer entirely from the circuit, and connects the neutral and polar relay through the center arm *u* of the switch and through the ground coil *Gc* to the ground G_2. In series with each dynamo is a lamp *l* or *l'*, having a resistance of 600 ohms. The various resistances are placed in boxes and means provided for readily adjusting both them and the condensers. The latter are usually placed under the table. The box *W* contains all the resistance coils for the artificial line; that is, the resistances *Rh*, *Cr*, and Cr_1, and, also, the ground coil *Gc*. *Nc* and *A B* represent the condenser and resistances, respectively, that are used in connection with the extra, or third, coil of the neutral relay.

FREIR SELF-POLARIZING RELAY.

186. In quadruplex telegraphy, where two messages are simultaneously sent in the same direction, one by reversals and the other by changes in current strength, a difficulty is encountered in accurately recording signals of the latter class that is due to a period of no current through the neutral relay at the moment of current reversal. The armature of the neutral relay when attracted by the stronger current will be momentarily released when the current is reversed and will make a movement toward the back or working contact, which, if completed, would cause a false signal.

The object that Mr. Freir had in view when designing his self-polarizing relay was to produce a neutral relay that would be very sensitive to changes in the strength of the current but which would avert, as far as possible, the false movement of the relay armature during the cessation of current at the moment of reversal.

187. The Freir relay, although called a self-polarizing relay, is, in reality, not a polarized relay. It does not respond to a change in the direction of the current, and, therefore, cannot be used except as a neutral device. Like all "common-side" relays, it is operated only by alterations in the *strength of the current*. It derives its name from the fact that its armature becomes alternately positive and negative by reversals of the current.

188. The **Freir self-polarizing relay,** shown in Fig. 64, has three parallel coils *A*, *B*, and *C* wound on soft-iron cores. To each end of each core is fastened a soft-iron extension that forms a pole piece, three of which *a*, *b*, and *c* are shown in the figure. There are two soft-iron armatures, one resting in the pole piece *b* and the other in a similar pole piece at the other end of the coil *B*. These armatures are fastened to an aluminum frame in the same manner as the armatures of the new standard Western Union polarized relay illustrated in Fig. 22. The magnets and armatures are enclosed in a brass case with a rubber top in a similar manner. The retractile spring *e*, in Fig. 64, tends to hold the tongue *D* against the stop *p*. The three electromagnets are connected in series, their coils, however, being so wound and connected that a current passing through them in one direction produces a south pole at *a* and *b* and a north pole at *c*. At the same time, the south pole at *b* produces, by induction or by actual contact, a south pole in that portion of the armature that is between the pole pieces *a* and *c*. Thus, with this direction of current, the south pole at *a* tends to repel and the north pole at *c* to attract the armature. If this current is strong enough, *D* will be moved from *p* against *q* and will remain there until the

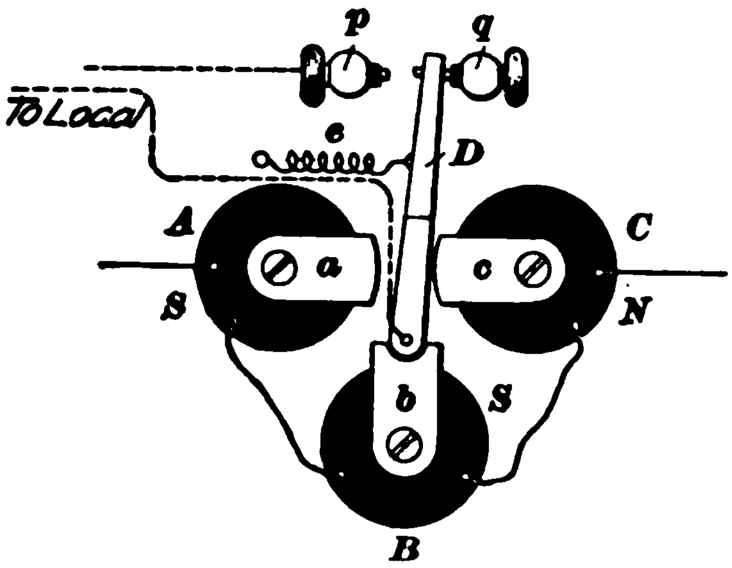


FIG. 64.

strength of the current is sufficiently diminished to allow the spring *e* to pull it against the stop *p*. Whenever the current is reversed by the operation of the distant pole changer, there will be a momentary cessation of current through the coils *A*, *B*, and *C*, but with a relay constructed in this manner, the momentary absence of current is not of sufficient duration to permit the armature to be sufficiently released to allow *D* to return to the back stop *p*. When the current is reversed, a north pole is produced in *a*, *b*, and in that portion of the armature that lies between *c* and *a*, while a south pole is produced in *c*. Hence *c* continues to attract the armature and *a* to repel it. Thus, although the magnetism of the several pole pieces is reversed, their respective attractions and repulsions remain unchanged.

189. This relay has proved to be a very satisfactory instrument. Aside from the self-polarizing principle, the absence of yokes, the small amount of iron in the cores of the magnet, and the excellent disposition of the cores, pole pieces, and armature, and the light weight and consequent small inertia of the moving parts, make this relay work very quickly and efficiently. Furthermore, it requires no condensers or other devices that are necessary on the neutral side of some quadruplex systems in order to tide the neutral relay over the interval of no magnetism while the direction of the current is being reversed.

190. Each coil of this relay consists of two separate windings, so that the relay can be connected differentially in the circuit the same as any differentially wound relay. Each half of the winding on one core contains about 2,350 turns of wire and has a resistance of 133⅓ ohms. This makes 400 ohms in the main-line and artificial-line circuits. The method of winding this relay is shown in Fig. 65, which is a view of the relay as it appears when looked at from above, all the details that might tend to complicate the figure being omitted. The binding posts are shown along the top of the figure. When the current flowing into the relay divides equally at *h*, half flowing out at *m* and half out at *o*, it will

be found by tracing the direction of the current in each coil around the iron core, that the two coils on each core neutralize each other; hence, the relay is not magnetized. If, however, the current does not divide equally at h, then the relay is energized and the armature will close the local circuit if the difference in the strength of the current in the two halves is sufficient to overcome the opposing spring.

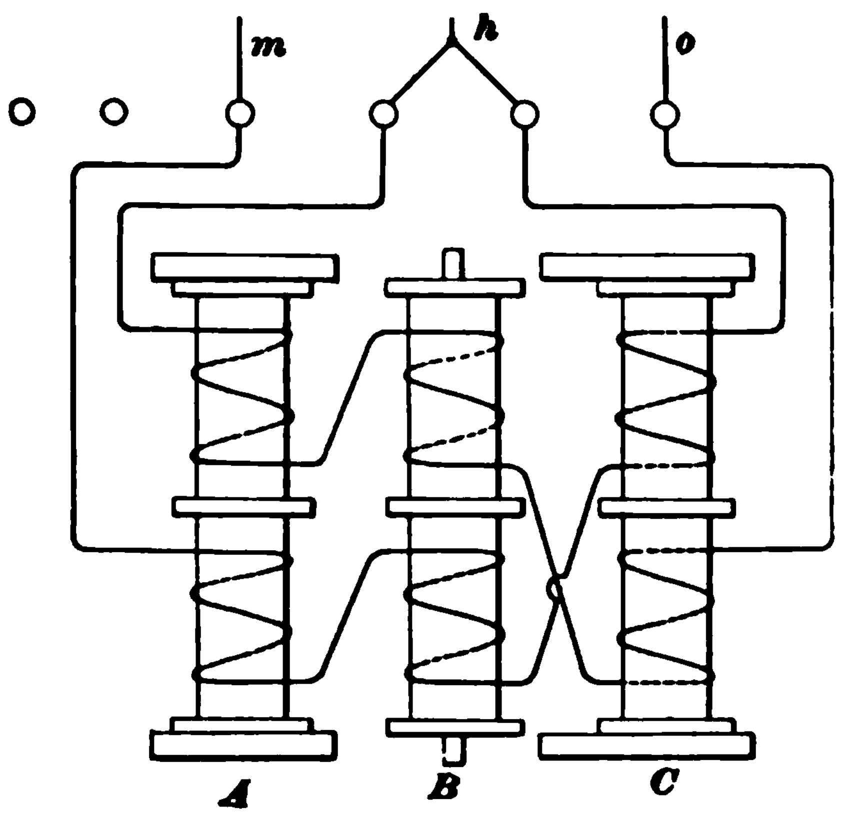


FIG. 65.

191. Adjustment. In order that the contact points of the Freir relay will not remain permanently closed, there is attached to the tongue a retractile spring that has a tension strong enough to keep the relay open when it is magnetized only by the smaller current employed in the quadruplex system. The adjustment of the spring is identical with that of the ordinary neutral relay.

The proper position of the armature lever between the two magnets is shown in Fig. 64. The space between the lever D and the pole piece a should, under ordinary conditions, be at least twice as great as that between armature D and pole piece c. Ordinarily c should be placed $\frac{1}{32}$ inch from the armature and a about three times that distance, or $\frac{3}{32}$ inch, from the armature. As the magnet A repels the armature and the magnet C attracts it, it is natural to suppose that if the magnet A were nearer the armature it would help C move the armature, but that is not the case. Under normal conditions the repelling magnet A should not help the magnet C do its work, and for that reason it is pulled away from the armature, as stated. If the repelling magnet is placed too close to the armature, the lines of force

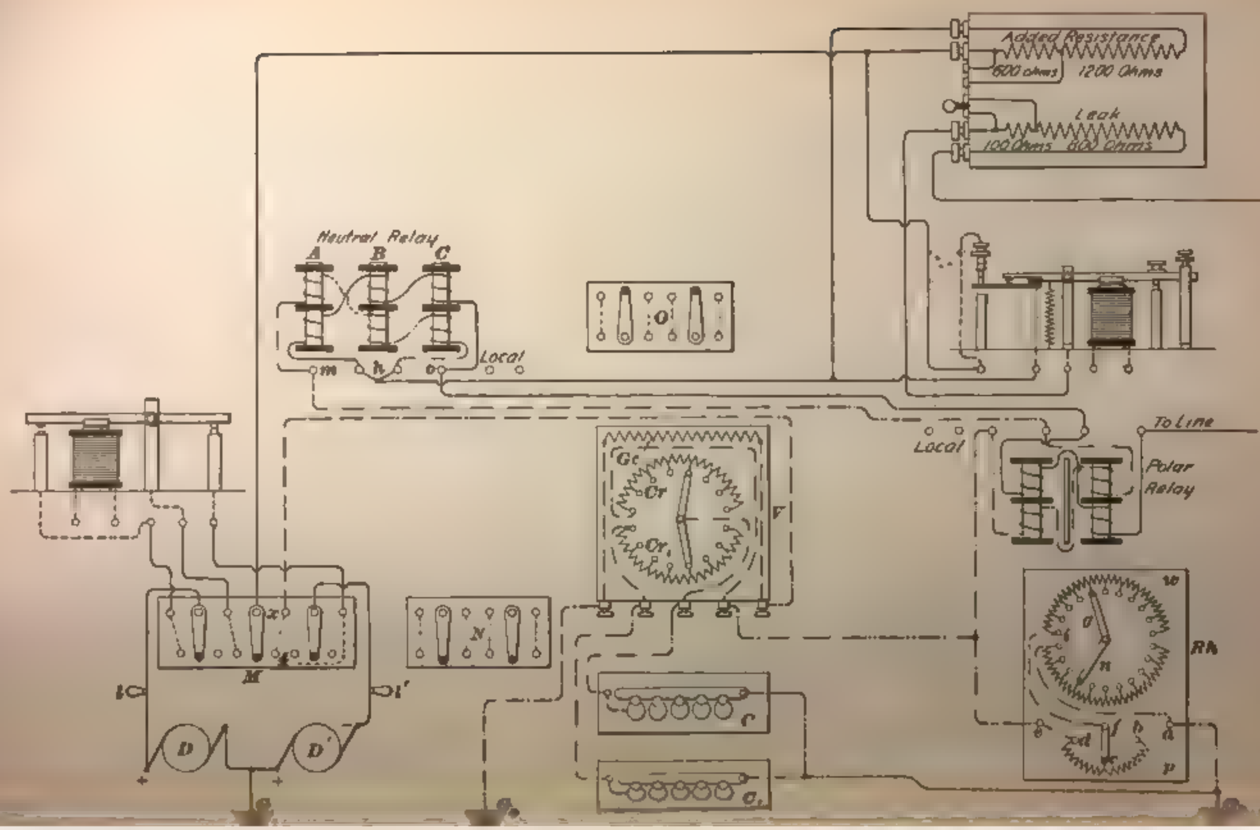
from C will cut through and weaken the polarity of the armature and so reduce the attraction of the latter for C.

The third coil may seem to be superfluous, and easily dispensed with. This is not the case, however, because it has, in practice, proved to be beneficial in bringing the repelling coil closer to the armature, when the effective current on a long circuit is weakened by the leakage due to wet weather and when the repelling magnet is actually needed in order to help a feeble incoming current move the armature. This enables the repelling lines of force to cross the intervening gaps in their endeavor to reach the opposite polarity, and their transit being in the same direction as those of the attracting magnet, the movement of the armature is accelerated by their combined strength.

A relay very similar to the Freir self-polarizing relay, but without the repelling coil, has been used in England. A strong point in favor of the third, or repelling, coil is found in the fact that the three-coil arrangement has given satisfaction where the English two-coil relay has failed.

NEW STANDARD WESTERN UNION QUADRUPLEX.

192. Fig. 66 gives the diagram of connections of the new standard quadruplex of the Western Union Telegraph Company, in which the new standard apparatus and dynamos are used. In order to keep the diagram as clear as possible, all sounders and local circuits have been omitted. They will be shown in Figs. 67 and 68. The apparatus to which it is desirable to call particular attention is the Freir self-polarizing relay, which is now being introduced in place of the ordinary three-coil neutral relay, the new form of polar relay, and the resistance boxes Rh and V, which are slightly different in form from any previously shown. The use of the Freir relay has improved the working of the system and does away with the condenser Nc and the coils A and B shown in Fig. 56, as they are not needed to bridge this relay over the interval of no magnetism due to the

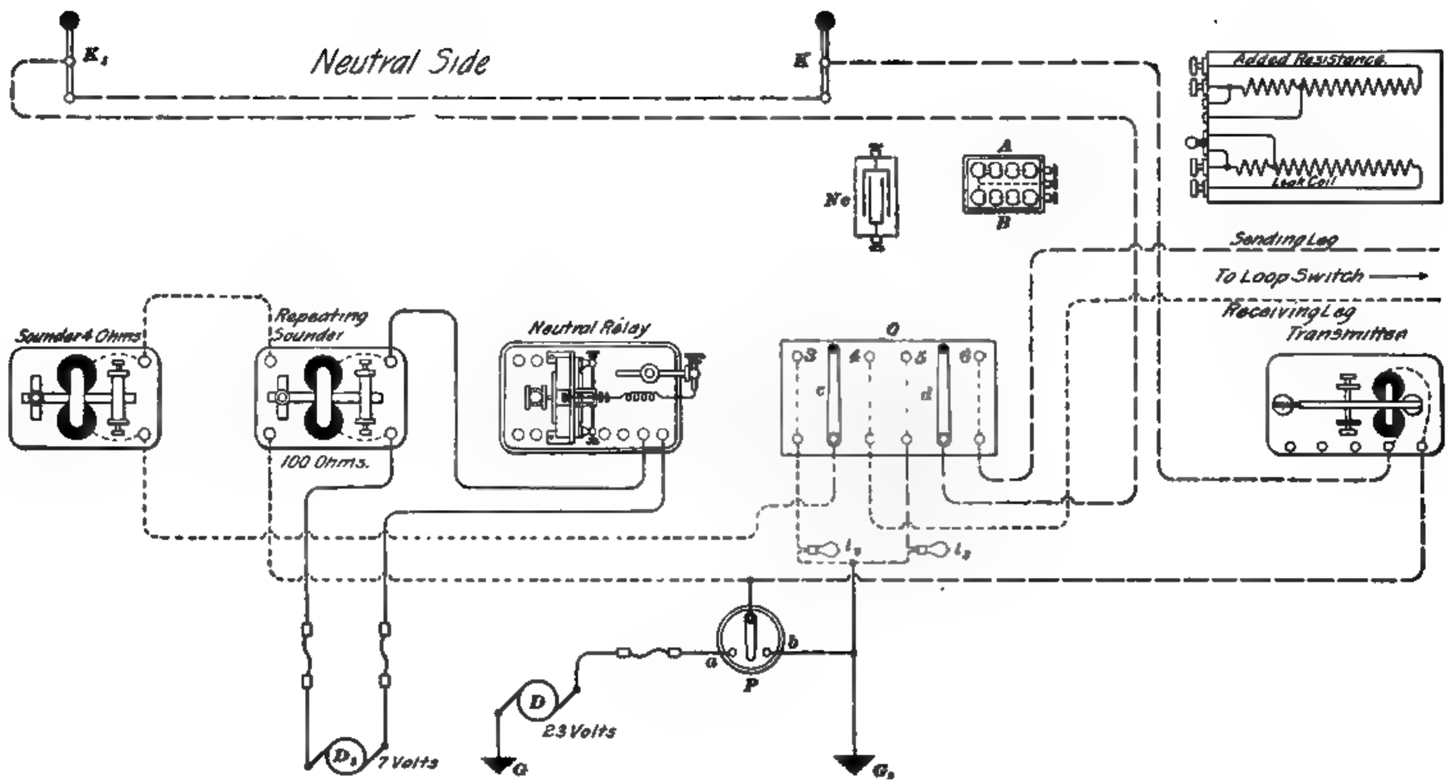


Added Resistance
600 ohms
1200 Ohms
Leak
100 Ohms
800 Ohms
Neutral Relay
A
B
C
Local
O
To Line
Polar
Relay
Local
Gc
Cr
Cr₁
V
RA
N
M
D
D′
C
C₁

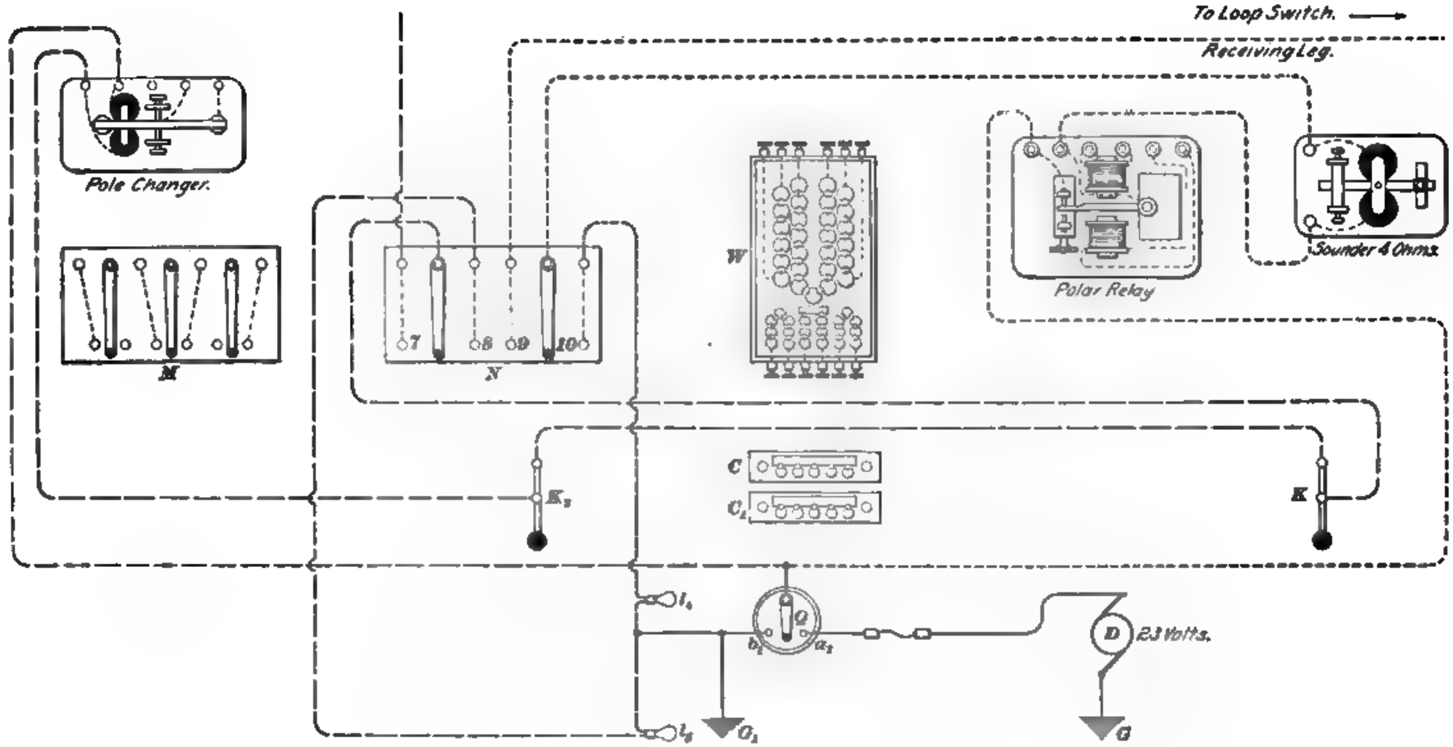
reversal of the distant pole changer. The Freir relay merely replaces the older form of neutral relay and does not change the principle of this quadruplex system in any way.

193. The resistance box *Rh* contains the resistance for the artificial line corresponding to *Rh* in Fig. 56. In Fig. 66 both the top *w* and the front *p* of the box containing the resistance *Rh* are shown. On the front *p* of the box is a switch arm *f* that connects the contact button *i* with any one of the contact buttons *b*, *c*, or *d*. Between these contact buttons are two coils, each of which has a resistance of 3,000 ohms. When the arm *f* rests on *b*, both of these coils are connected in series in the artificial-line circuit; when the arm rests on *c*, one of these coils is cut out; and when it rests on *d*, both coils are cut out. The arm *g* on the top of the box makes a contact with any one of eleven buttons; the arm *n* may similarly be placed in contact with any one of eleven buttons. The amount of resistance in the circuit between *a* and *e* depends on the positions of the arms *g*, *n*, and *f*. There are ten coils in the upper part of the rheostat *Rh*, each coil having 400 ohms resistance, and ten coils in the lower part of the same box that have 40 ohms resistance each.

194. The box *V* contains a coil *Gc*, corresponding to the ground coil *Gc*, in Fig. 56. This coil is included in the circuit for the purpose of balancing the system. The ground coil *Gc*, which need not be adjustable, has a resistance of 600 ohms, which is equivalent to the resistance of the lamp in each dynamo circuit. The coils *Cr* and Cr_1 are adjusted by means of two radial arms. These coils correspond to the coils *Cr* and Cr_1, respectively, in Fig. 56, and the condensers *C* and C_1 correspond to the condensers *C* and C_1, respectively, in the same figure. The total resistance in the upper, or *Cr*, portion of the box is 525 ohms, and the total resistance in the lower, or Cr_1, portion of the box amounts to 1,000 ohms. Thus the resistance *Cr* may be adjusted from 0 to 525 ohms, and the resistance Cr_1 from 0 to 1,000 ohms. Usually, the condenser *C* should have about



Neutral Side
K_1
K
Added Resistance
Leak Coil
Ne
A
B
Sending Leg
To Loop Switch
Receiving Leg
Transmitter
Sounder 4 Ohms
Repeating Sounder
100 Ohms.
Neutral Relay
O
3
4
5
6
c
d
l_1
l_2
a
b
P
D
23 Volts
D_1
7 Volts
G
G_1



To Loop Switch.
Receiving Leg.
Pole Changer.
M
N
7
8
9
10
W
Polar Relay
Sounder 4 Ohms.
K
K2
C
C1
Q
D
23 Volts.
G1
G

FIG. 68.

twice the capacity of C_1, since it equalizes the charge on the near end of the line, which is greater than the charge toward the center of the line. This charge is to a large extent equalized by the condenser C_1. These radial-arm resistance boxes are not extensively used, because operators have found that boxes requiring the use of plugs in their adjustment are more reliable, because plugs make firmer connections than do the radial arms.

195. The switch M has already been shown in connection with quadruplex and duplex systems. When the three arms of the switch rest on the left-hand contact buttons, the apparatus is properly connected for use. In order to balance the quadruplex, the switch arm x should be turned to the right until it rests on the contact button *4*. This cuts off both dynamos, the transmitter, and the pole changer, and connects the receiving apparatus directly to the ground through the ground coil *Gc*.

196. Local Connections.—Figs. 67 and 68 show the connections for the local circuits of the Western Union quadruplex system when dynamos are used. Fig. 67 represents the neutral, common, or No. 2, side of a complete set. Fig. 68 represents the polar, or No. 1, side. In this figure, in order that the apparatus and connections on the neutral side may appear to the student as they would if he were facing that side of the table instead of the polar side, it is only necessary for him to look at the figure upside down. In both of these figures the apparatus is arranged and lettered the same as it is in Fig. 63. The local circuits for Fig. 66 would be connected in the manner shown in these two figures. The repeating sounder that is controlled by the neutral relay is operated by the 7-volt dynamo D_1, which is used for operating all repeating and ordinary 100-ohm sounders in the main office of this company. All 4-ohm sounders, pole changers, and transmitters are supplied with current from the same 23-volt dynamo D.

The local circuits are so arranged that they may be extended through the loop switchboard to a branch office. On

the neutral side, shown in Fig. 67, the receiving circuit is controlled by the repeating sounder, which, in turn, is controlled by the neutral relay. On the polar side, shown in Fig. 68, the receiving circuit is controlled by the polar relay. Both receiving circuits are shown by dotted lines; the sending circuits, one of which includes the pole changer and the other the transmitter, are shown by dash lines. It will be noticed that two keys are placed in each of the sending circuits; the second key in each circuit is to enable the receiving operator to break and communicate with the distant end without having to leave his position. Of course, it is only allowable for him to break when the sending operator on that side is not using his key.

197. The switches O and P in Fig. 67 and N and Q in Fig. 68 are used in the same manner as are those that were described in connection with the polar duplex. When the system is in operation and the local circuits are not to be extended to any branch office, the arms of the switch N should rest on the contact buttons *8* and *10*; the arms c and d on the contact buttons *3* and *5*; and the switches P and Q on the contact buttons a and a_1, respectively. With the switches in this position, the receiving circuit on the neutral side, Fig. 67, may be traced from the ground G through the 23-volt dynamo D, contact button a, arm of the switch P, contact points of the repeating sounder, the magnet of the reading sounder, the switch arm c, contact button *3*, the lamp l_2, to the ground G_1. The transmitter circuit may be traced from the ground G through the 23-volt dynamo D, contact button a, arm of the switch P, the magnet of the transmitter, keys K and K_1, the switch arm d, contact button *5*, the lamp l_2, to ground G_1. The two circuits on the polar side may be traced in the same manner, and the student should be able to do this for himself.

198. When the receiving and sending circuits are to be extended to branch offices, the sending and receiving legs on one side are ordinarily connected to one branch office,

and the sending and receiving legs on the other side to another branch office. It is not necessary that both sending and receiving circuits should be extended to the same branch office. The branch offices are able to receive the messages that are coming in through the neutral and polar relays, and to send out messages by controlling the transmitter and pole changer. In order to extend these receiving and sending circuits to branch offices, the arms of the switch *N*, in Fig. 68, are turned to the left until they rest on contact buttons *7* and *9*, and the arms of the switch *O*, in Fig. 67, are turned to the right until they rest on contact buttons *4* and *6*; the arms of the switches *P* and *Q* remain on buttons a and a_1 as before.

The receiving circuit on the neutral side, shown in Fig. 67, may be traced from the ground *G* through the 23-volt dynamo *D*, switch *P*, contact points of the repeating sounder, the magnet of the reading sounder, the switch arm *c*, contact button *4*, the receiving leg to the loop switchboard, the main switchboard and line wire to the branch office, and then through a sounder to the ground at the branch office. The sending circuit on the same side may be traced from the same ground *G*, through the 23-volt dynamo *D*, the switch *P*, the magnet of the transmitter, keys *K* and K_1, the switch arm *d*, contact button *6*, sending leg to the loop switchboard, the main switchboard and line to the branch office, and then through a sounder and key to the ground at the branch office. The connections through the loop switchboard and the branch office are exactly the same as those shown in connection with branch-office circuits in the polar duplex system. It will be noticed that the lamps l_2, l_3, l_4, and l_6 are not in the circuit when the arms of the switches *N* and *O* are turned so as to extend the circuits to the loop switchboard and branch offices. Each one of these lamps has a resistance equal to the resistance in one leg of the branch-office loop, so that the current through the sending and receiving sides is the same in both positions of the arms of the switches *N* and *O*. When the sets are not in use, all connections with the 23-volt dynamo are

broken by turning the switches P and Q to the contact buttons b and b_1, respectively.

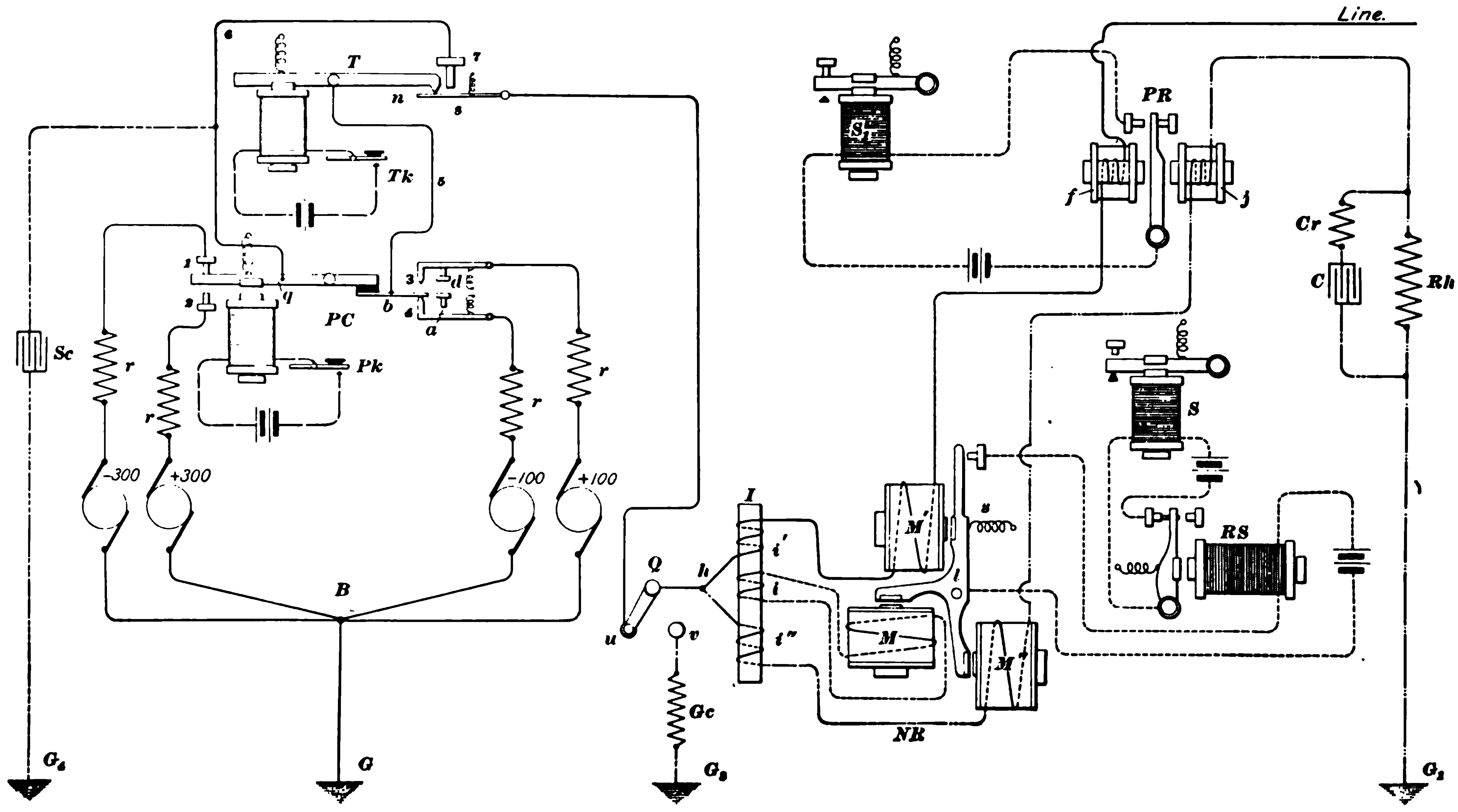
199. The quadruplex apparatus shown in Figs. 67 and 68 is arranged on a large table that is divided into four parts, one quarter being for each operator. Sitting side by side are two operators, one of whom is sending through the pole changer while the other is receiving through the polar relay. Facing these two operators are the other two, one of whom is sending through the transmitter while the other is receiving through the neutral relay.

JONES QUADRUPLEX SYSTEM.

200. The quadruplex system used by the Postal Telegraph Company is known as the **Jones quadruplex,** from its inventor, Mr. F. W. Jones. Its principal features are shown in Fig. 69.

Dynamos are used for generating the current for the line and local circuits. For operating the main-line circuits, four machines are used. They are adapted, respectively, to deliver current to the line at the following pressures: one +130 volts, one −130 volts, one +350 volts, one −350 volts. On different lines, different voltages are used; the lower electromotive force ranging from 75 to 135 volts, and the higher from 225 to 400 volts. 100-volt and 300-volt machines are indicated in the figure merely for convenience in explaining the system. These machines each have one of their poles connected to a common ground G.

201. PC is a pole changer that is worked by the key Pk in the local circuit. The pole changer, which has a slightly different construction than any previously shown, serves simply to control the polarity of the current going to the line. T is a transmitter that is worked by the key Tk in a local circuit and serves simply to control the strength of the current going to the line, irrespective of its polarity. The two parts of the lever of the pole changer are insulated from



Line.
T
n
s
7
Tk
5
PR
f
j
Cr
C
Rh
1
2
3
d
q
b
a
PC
Pk
Sc
r
-300
+300
-100
+100
B
G
Q
h
u
v
Gc
I
i'
i
i"
M'
M
M"
l
s
S
RS
NR

each other at *b*. This pole changer makes contact either at *1* and *4* or at *2* and *3*; *1* and *2* are fixed contact stops while *3* and *4* are spring contacts. The lever, when it moves upwards, may be made touch the spring *3* before it leaves the spring *4*; and when it moves downwards, it may be made touch the spring *4* before it leaves the spring *3*, thus making a continuity-preserving pole changer only at the lower voltage end. The stops *a* and *d* may be adjusted until the circuit is reversed in this manner. Thus in the middle position of the lever, the two machines −100 volts and +100 volts are momentarily in series and preserve a continuous circuit from the lever of the transmitter *T* to the ground *G*. The higher voltage machines are not arranged in this manner because the sparking at the contact stops *1* and *2* would be injurious.

202. Non-inductive resistance coils *r*, usually of 800 ohms each, are connected directly in series with each dynamo. A condenser *Sc*, called the **spark condenser,** is generally connected between the lever *q* of the pole changer and the ground, in order to reduce the spark at the contact stops *1* and *2*, which are connected to the higher voltage dynamos. The extra current that otherwise would cause a bad spark when the circuit is broken at either stop *1* or *2* is opposed by the discharge from the condenser *Sc*, thus preventing the spark, or at least reducing its intensity.

203. Jones Neutral Relay.—*N R* is a triple-magnet relay wound differentially, but not polarized, and, therefore, responding to currents in either direction. It is a special form of a neutral relay. The spring *s* is so strong that incoming currents from the distant 100-volt dynamos will not close the relay, but those from the distant 300-volt dynamos will. The two electromagnets *M′* and *M″* are magnetically independent of each other in the sense that their cores are not magnetically connected in any manner, but they act in conjunction upon one armature lever. The cores are made as short as possible and have a very narrow slot running to the center of the core. This slot is for the purpose of cutting

off induced, or eddy, currents. The magnets M' and M'' are balanced with respect to outgoing currents in the ordinary manner, and although not so shown in this figure, each core has two separate coils, connected respectively in the main and artificial lines as shown in Fig. 70. The two coils on each magnet oppose each other when outgoing currents are flowing through them.

As the two magnets pull in conjunction on the same armature lever, when an unbalanced current circulates through the line and artificial-line coils, the magnetic effect of arriving currents is augmented; and as the cores of these magnets are independent of each other, the time required for the reversal of the magnetism of both cores is not increased beyond that incurred were only one of them in circuit. It is thus possible to preserve, or prolong, the magnetic pull of the neutral relay by reducing the time of reversal of the magnetism in the cores. M is a smaller magnet that acts on a third arm of the armature lever. The magnetic pull of this magnet assists the pull of the other two magnets.

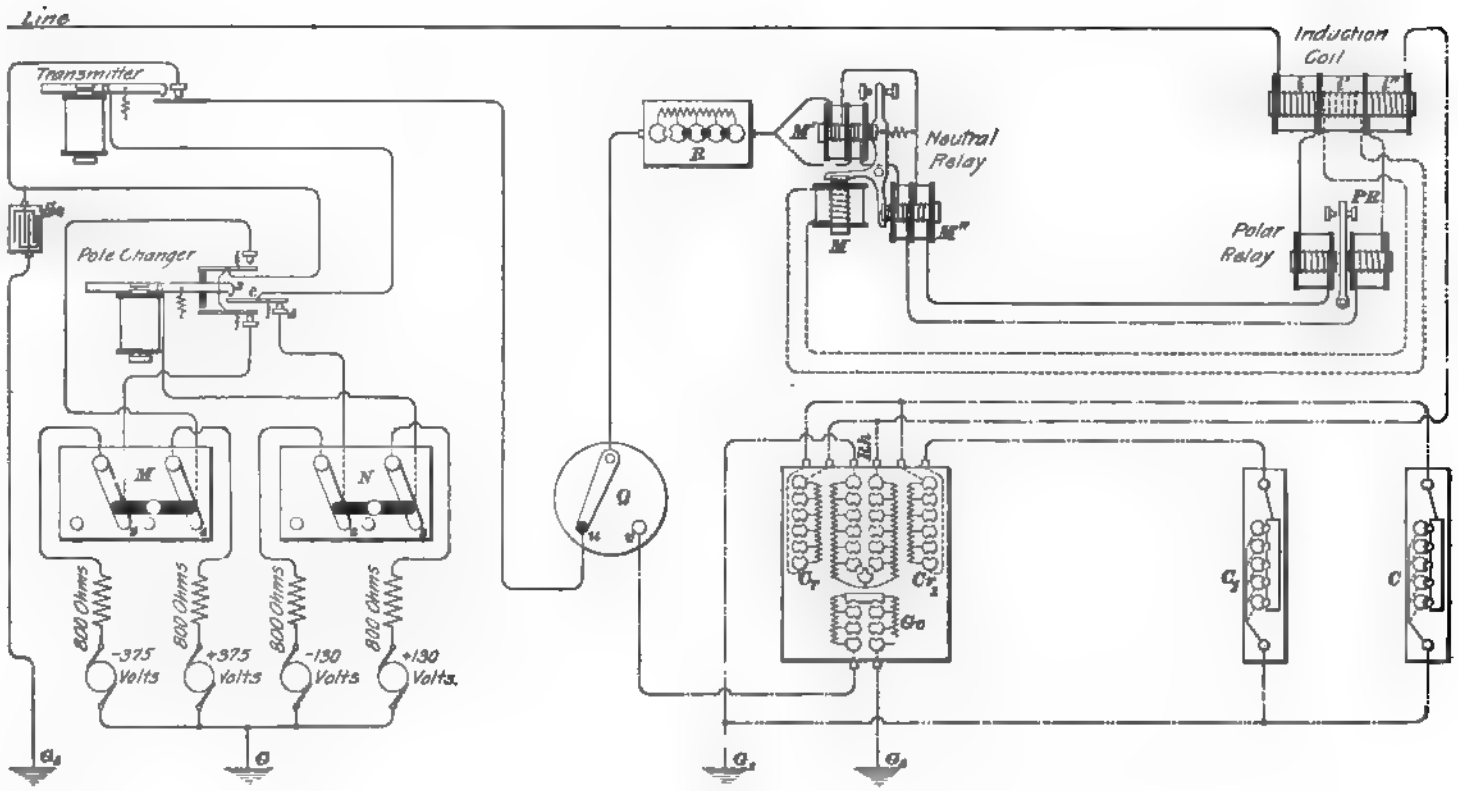
The armature of the relay is made of aluminum and is very carefully balanced. The retractile spring s and the magnets M' and M'' have all the adjustments found in an ordinary relay. The magnets occupy the positions shown in the figure; that is, M is below M' and about on a level with M''.

204. I, in Fig. 69, is an induction coil having two primary coils i' and i'', and one secondary coil i. The magnet coils M' and M'' and the two primary coils i' and i'' are differentially wound. The coil i' is connected in series with M' in the line circuit, and i'' in series with M'' in the artificial-line circuit. The object of this device is to prevent the mutilation of the signals received by the neutral relay, by preventing the armature from falling back upon the back stop when it should not do so. One of the primary coils of the induction coil I is wound and connected so as to neutralize the effects of the other primary coil. Under the

influence of currents for outgoing signals, the secondary coil i of the induction coil has no current induced in it, because the two primary coils neutralize each other's effects. But incoming currents passing through the primary coil will induce an instantaneous current in the secondary coil i, which passing through the magnet coil M will magnetize it. The effect of the current thus set up in the secondary coil and made to act on the neutral relay is adjusted so that the induced secondary current will not be sufficient to pull the armature away from the back stop. When, however, the armature lever is against its front stop, and, therefore, in closer proximity to the core of the relay, the secondary current will be sufficient to hold up the armature, although the strength of the current in the coils M' and M'', consequent upon a reversal of polarity, may momentarily cease.

Suppose that while the lever of the transmitter T is depressed, in order to transmit a dash on the neutral side, the lever of the pole changer moves from its depressed to its raised position. The electromotive force in the circuit will change from $+300$ to -300, and, therefore, the current passing through the home relay will change in direction, and in so doing, it will pass through its zero value. This change in direction will tend to suddenly release the armature of the neutral relay and reattract it, thus tending to break the dash that the relay NR is receiving. The change in the current passing through the coil i' will induce a current in the coil i that will pass through the coil M and that will be at its maximum strength as the current in the line and coil i' passes through zero. This current, therefore, acts on the armature l to prevent it from fluttering and touching the rear stop when it should remain against the front stop. The current induced in the secondary coil i is always strongest when most needed; that is, when the current in the line is varying most rapidly, as it does when it passes through zero.

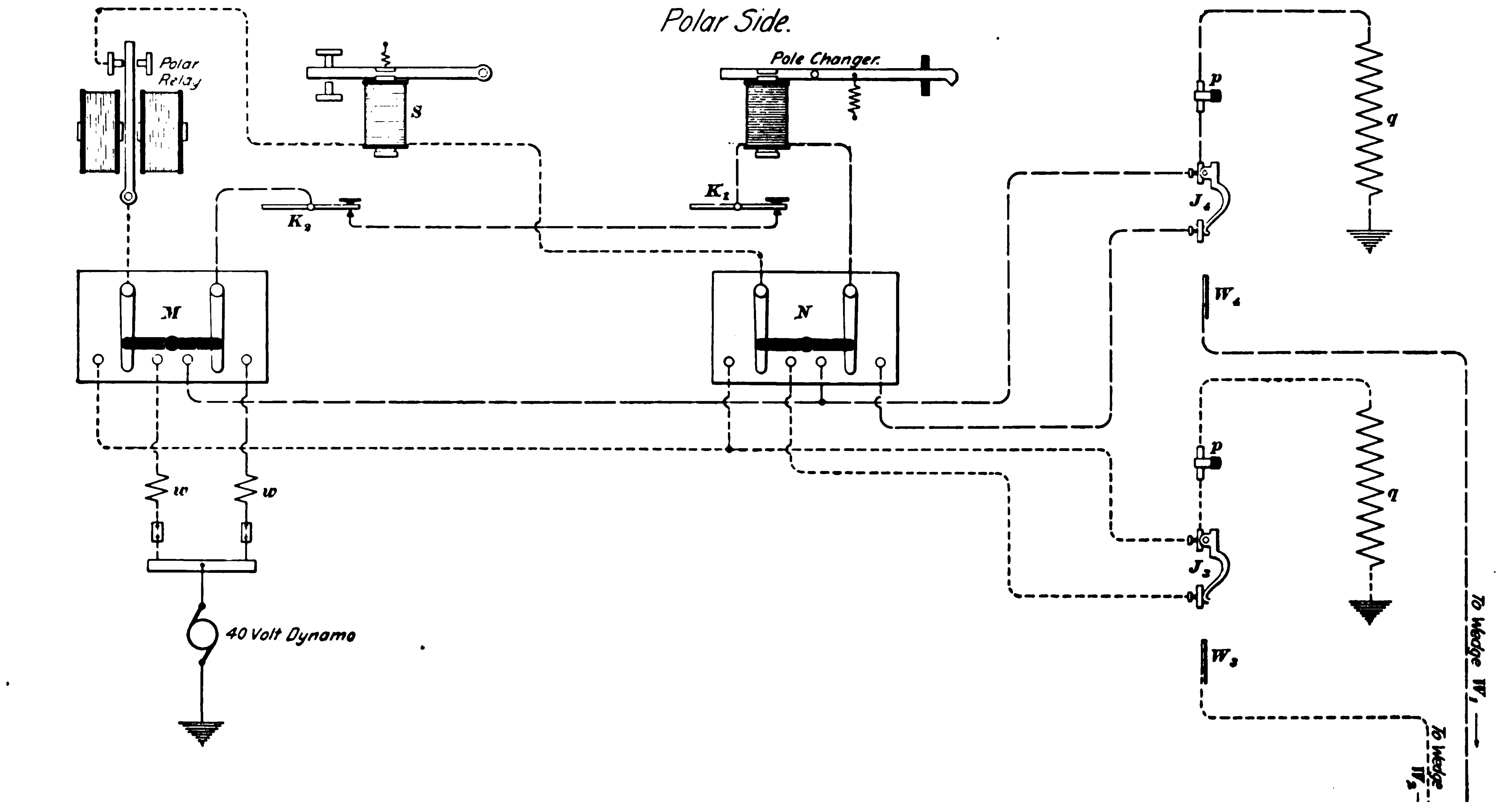
205. PR is a differential polarized relay, responding to positive currents coming from the distant station, but held



Line
Transmitter
Pole Changer
M
N
800 Ohms
-375 Volts
+375 Volts
-130 Volts
+130 Volts.
Q
R
Neutral Relay
Induction Coil
Polar Relay
PR
C

connected to the ground, while from the other pole leads are taken through non-inductive resistance coils of about 30 ohms, to the various sounders, the magnets of the pole changer and transmitter, to the ground. This arrangement of the local receiving and sending circuits will be shown more fully in Figs. 71 and 72. The switch Q in Fig. 69 is used for grounding the circuit through the coil Gc, leaving all transmitting apparatus cut off. This is for the purpose of balancing and properly adjusting the relays to incoming currents from the line. The resistances Rh and Cr and the condensers C constitute the artificial line, which is adjusted in the manner explained in connection with the duplex systems.

212. Practical Arrangement.—The practical arrangement of the apparatus in the Jones quadruplex system is shown in Fig. 70. This figure is lettered the same as the preceding one. The switches M and N, to which the dynamos are connected, are located on the desks on which the quadruplex apparatus is placed. They are used in this case simply to connect and disconnect the dynamos. When the quadruplex set is in use, the switches M and N are pushed to the right so that the arms rest on the contact buttons *2*, *4*, *6*, and *8*. When the arms are in the intermediate, or left-hand, positions all the dynamos are cut off. The pole changer, although somewhat different in form from that shown in Fig. 69, accomplishes exactly the same result. The higher voltage machines are never short-circuited. The lower voltage machines, however, are momentarily short-circuited when the lever is in the middle position, because the lever *3* touches the lever c before the latter is pushed away from the stop *4*. The interval during which the lower voltage machines are short-circuited is extremely small. All resistance coils are contained in one box, the circuits through which are plainly indicated. The two condensers C and C_1, the adjustable resistances Cr and Cr_1, and the resistance Rh constitute the artificial line. The magnets M' and M'' of the neutral relay each have two coils,



Polar Side.
Polar Relay
S
Pole Changer.
K_2
K_1
M
N
p
q
J_4
W_4
J_3
W_3
w
w
40 Volt Dynamo
To Wedge W_1
To Wedge W_2

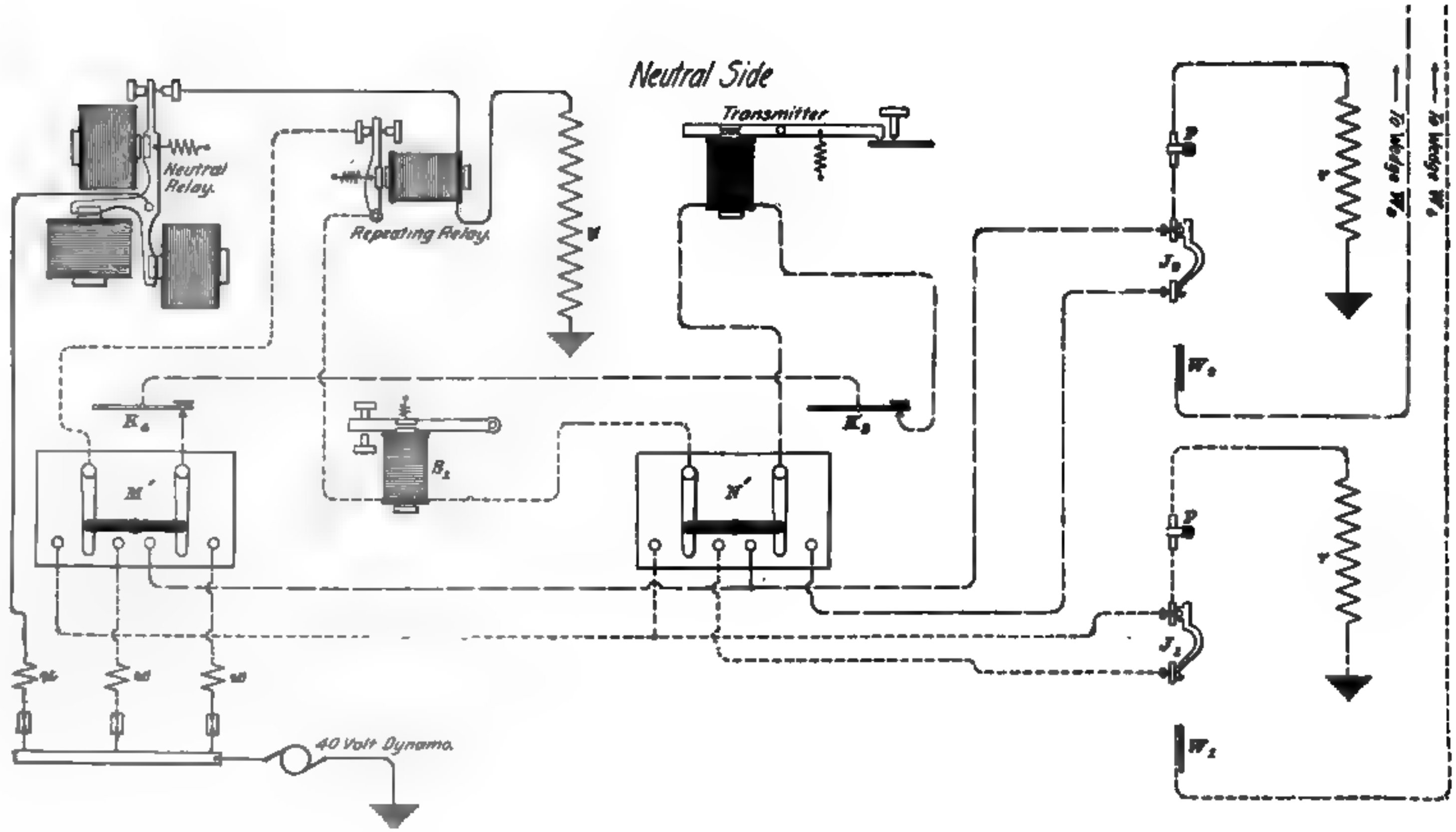

Neutral Side
Transmitter
Neutral Relay.
Repeating Relay.
40 Volt Dynamo
M'
N'

FIG. 92.

as shown, one coil on each magnet being connected in the line circuit, and one in the artificial-line circuit. The two coils on the one magnet oppose each other when they are both supplied with current from the home-station dynamos.

213. Between the contact button *v* of the switch *Q* and the ground G_3 is the ground coil *Gc*. It is equal in resistance to that of the circuit through the transmitter, pole changer, 800-ohm resistance coil, and dynamo to ground *G*. The resistance of this latter circuit, exclusive of the 800-ohm non-inductive resistance coil, is practically negligible and, hence, *Gc* is practically equal to the resistance of that coil, that is, 800 ohms. When the arm of the switch *Q* is turned to the contact button *v*, the resistance of the home quadruplex set from the line to the ground is evidently the same as when the arm is on the contact button *u*. The arm of the switch *Q* is placed on contact button *v* when the system is being balanced.

214. Local Connections.—The local connections for both the polar and neutral sides of the Jones quadruplex system, for use in an office having a loop switchboard and dynamos, are shown in Figs. 71 and 72. The arrangement of the loop switches shown in these figures is that employed by the Postal Telegraph Company, and differs somewhat from the arrangement of the loop switches of the Western Union Telegraph Company. The upper part of each jack on the loop switchboard is connected through a pin plug *p* and a resistance *q* to the ground. When the pin plug *p* is removed, the upper part of the jack is disconnected from the ground. When the quadruplex set in a main office is not to be connected with any branch office, nor arranged so that it will repeat into another quadruplex set, the pin plugs *p* will all be in place, there will be no wedges in the jacks, the switches *M* and *M'* will be turned toward the right, and the switches *N* and *N'* will be turned toward the left. With the apparatus arranged in this manner, the receiving circuit on the polar side may be traced from the dynamo through the switch *M*, the polar-relay contact points, the

sounder S, the switch N, the jack J_2, the pin plug p, resistance coil q, and back through the ground to the dynamo.

The student should now be able to trace the sending circuit on the polar side, and also the sending and receiving circuits on the neutral side. On the neutral side, the circuit through the contact points of the repeating relay or sounder and the magnet of the ordinary sounder S_1 resembles that through the contact points of the polar relay and the magnet of the sounder S on the polar side. The contact points of the neutral relay and the magnet of the repeating relay are in a third separate, or independent, circuit between the dynamo and the ground. The non-inductive resistance coils are made of German-silver wire, and have about the following resistances: r, r, 120 ohms each; y, 170 ohms; q, q, 130 ohms each; w, w, w, w, 30 ohms each; and u, 30 ohms.

215. One Set Repeating Into Another.—When it is desirable to repeat from one quadruplex set into another, it is only necessary to connect the loop switches on each side by means of flexible wires terminating in wedges that are insulated on one side, and to turn the switches M, N, and N' toward the right, and M' toward the left; or M may be turned toward the left, and M', N', and N toward the right. That is, by inserting the wedge W_2 in the jack J_2, and the wedge W_3 in the jack J_3, the receiving corner of the polar side of one quadruplex set may be made to repeat into the sending corner of the neutral side of a second quadruplex set. And by inserting the wedge W_1 into the jack J_1, and the wedge W_4 into the jack J_4, the receiving corner of the neutral side of the second set may be made to repeat into the sending corner of the polar side of the first quadruplex set.

The student should be able to trace out the circuits for himself, and should also understand that when the wedges are inserted in the manner described above, the polar and neutral sides shown here will belong to two entirely different quadruplex sets. For instance, the polar side may belong to the quadruplex system extending from New York to Buffalo, and the neutral side to the quadruplex system

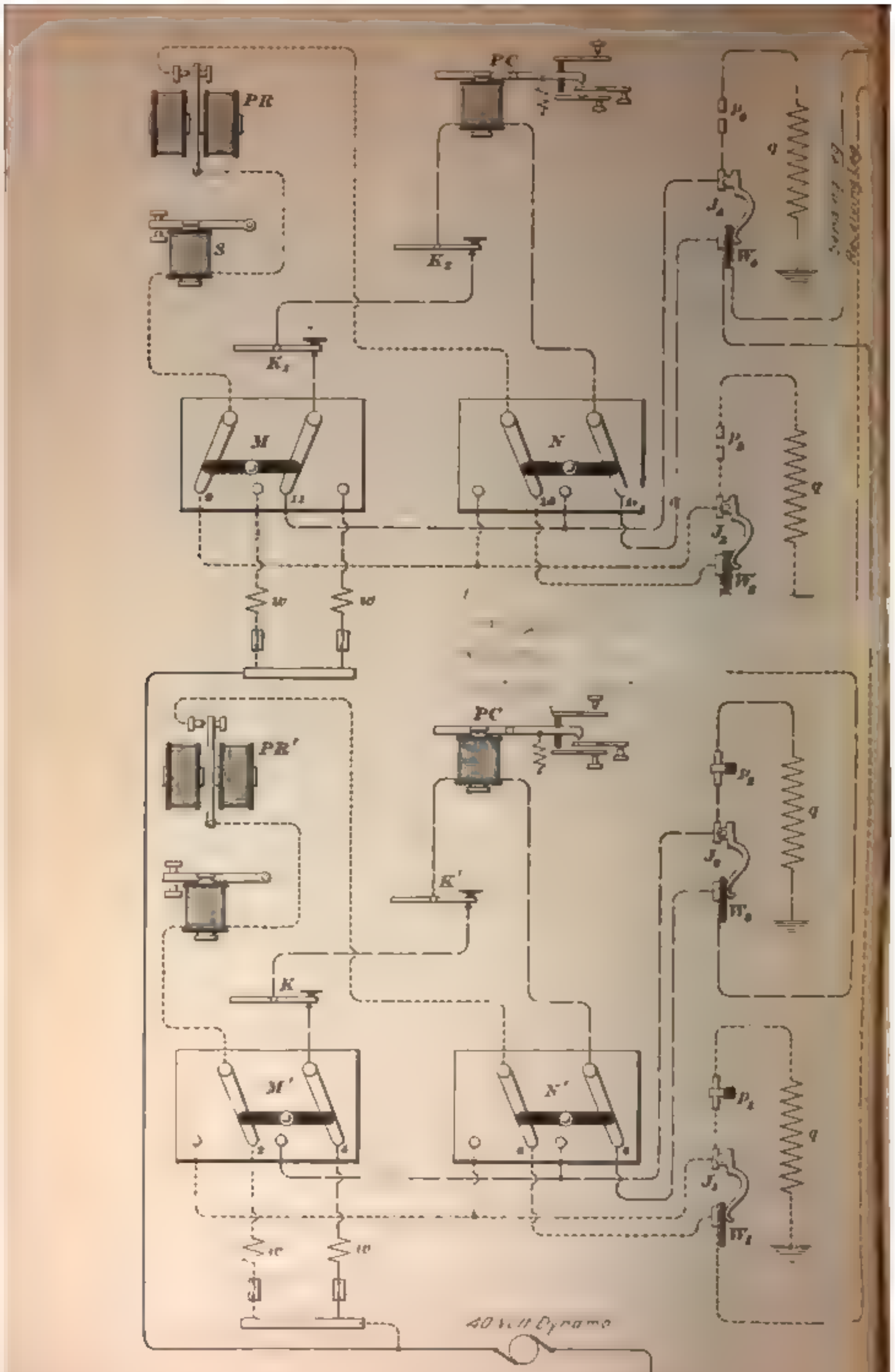


Fig. 73.

extending from New York to Baltimore. Therefore, when the jacks are connected together by means of cords terminating in single wedges, in the manner just explained, we have the polar side of the Buffalo quadruplex repeating into the neutral side of the Baltimore quadruplex set.

In order to change this arrangement, so that one side will no longer repeat into the other, it is only necessary to turn the switches M and M' toward the right, and N and N' toward the left. Each side will then work independently.

216. Postal Telegraph Loops.—The Postal Telegraph Company's loop system is further illustrated in Fig. 73. This figure shows a method employed for connecting a branch office with the quadruplex set, so that the branch [illegible] [illegible]d send on another. When the [illegible] left, the switches N, M', and N' toward the rig[illegible] plugs p_3, p_4 removed, and the single wedges W_1 and W_2 inserted in the jac[illegible], and J_2, and two single wedges W_3 and W_4 inserted in each of the jacks J_3 and J_4, respectively, the polar relay PR controls the pole changer PC', and also sends its message through the receiving leg to the branch office, which is not included, however, in this figure. Thus the message that is received on the polar relay PR is sent to the branch office and, by means of the pole changer PC', is repeated into another quadruplex set and is thus sent to another distant main office. This circuit may be traced from the ground G, through a 40-volt dynamo, fuse, resistance w, contact button 4 on switch M', the keys K and K', the pole changer PC', switch N', contact button 8, jack J_2, wedge W_2, wedge W_1, jack J_1, contact button 14 on switch N, contact points of the polar relay PR, sounder S, switch M, contact button 9, jack J_3, wedge W_3, receiving leg of the branch-office loop, and through the branch-office sounder (not shown in this figure) to the ground. It will be seen that when the plug p_3 at the jack J_3 is removed, the receiving leg of the branch-office loop circuit replaces the resistance q that is connected between the ground and the upper part of this jack.

The other circuit through the polar relay PR', the pole changer PC, and the sending leg of the branch-office loop may be traced in a similar manner. In order to disconnect the branch-office loop, and to make the two circuits work independently of each other, it is only necessary to replace the plugs p_3 and p_4 and to turn the switches M and M' toward the right, and N and N' toward the left.

217. With all the wedges and the pin plugs p_1 and p_2 in place, the three switches N, M, and N' turned toward the right, and M' toward the left, the two circuits will repeat into each other. In this case it is immaterial whether the pin plugs p_3 and p_4 are in or out of place.

With the plugs p_3 and p_4 removed, and the three switches M', N', and N turned toward the right, and M toward the left, the two circuits not only repeat into each other, but the message is sent to the branch office, as explained in Art. **216.** Furthermore the branch office, by operating the key in the sending leg, can send a message through the pole changer PC, provided PR' remains closed, to the distant main office that is connected with the contact points of the pole changer PC. By operating a key in the receiving leg, the branch office can send a message through the pole changer PC' to the other distant main office that is connected with the contact points of the pole changer PC'. Thus two messages can be sent simultaneously from the branch office, one to each terminal office; however, the terminal offices cannot send on the same side of a quadruplex, and not at all on a duplex system at the same time; hence, in the latter case the system is only worked single, and not duplex. This will be more fully explained under the heading of "Multiplex Repeaters."

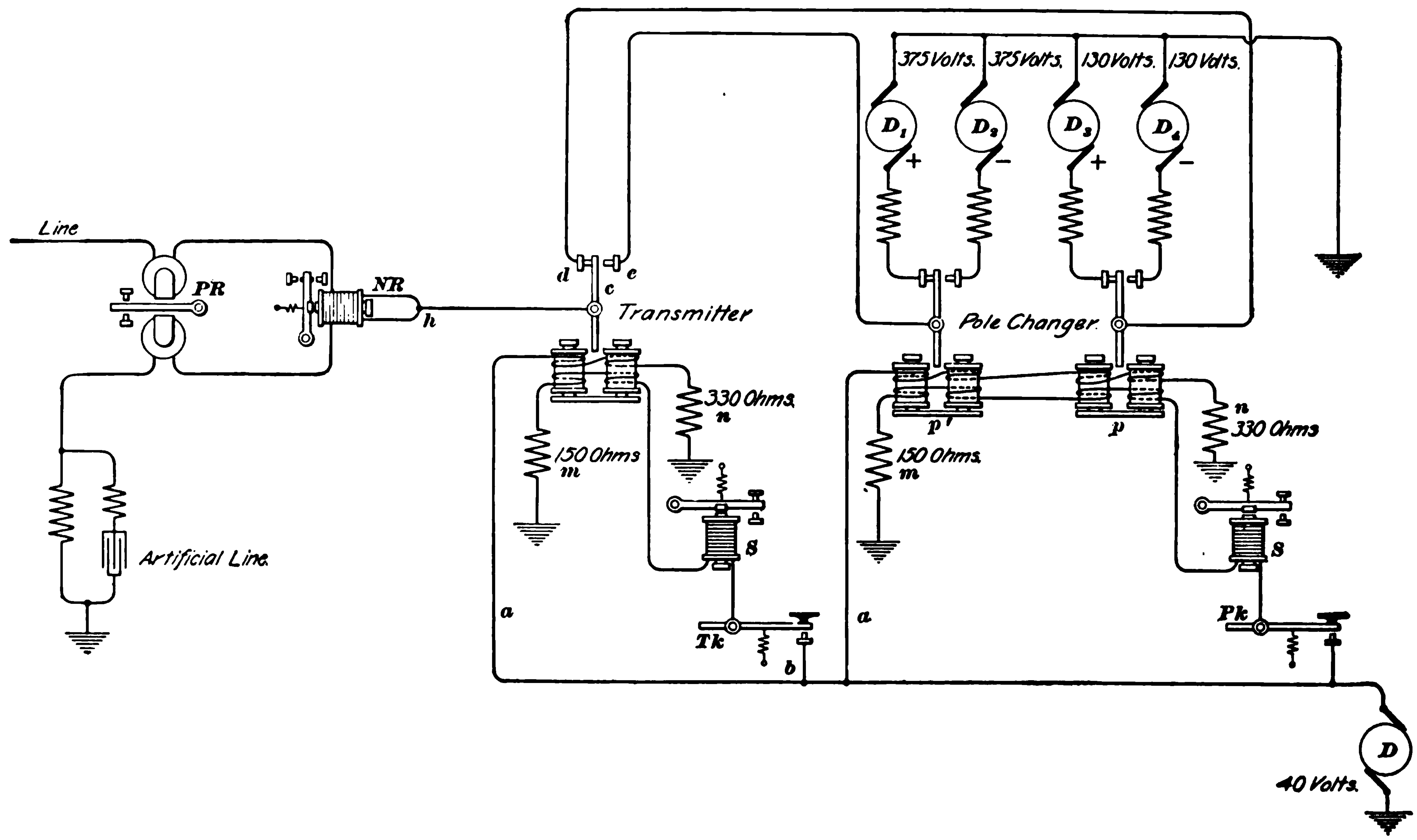
HOUGHTALING POLARIZED TRANSMITTER AND POLE CHANGER.

218. A polarized transmitter and pole changer that do not depend in any way on springs for their operation have been introduced on some of the Postal Telegraph Company's

fastest circuits, where they are reported to have done excellent work. These instruments, which are intended for use in connection with multiplex telegraph systems, are the invention of Mr. W. A. Houghtaling, and are known as the **Houghtaling polarized transmitter and pole changer.** They are shown in Fig. 74 in connection with the ordinary quadruplex key system of the Postal Telegraph Company, but are, however, applicable to any of the common systems. The local magnets of the transmitter and pole changer are provided with double windings, one of which is connected permanently in circuit with the dynamo *D* through a resistance *n*, and the other through a key, reading sounder *S*, and resistance *m*, so arranged that the current passes in opposite directions through the two windings around the cores of the transmitter and pole changer. The resistance coil *n* in the permanent circuit has such a value that the strength of the current in this circuit is one-half that in the key circuit; or, in other words, the total resistance of the permanent circuit is double that of the circuit that includes the key and sounder.

With this key system, two of the polarized instruments mounted on one base form the pole changer, and one, separately mounted, is used as a transmitter. As the action of the local circuits is the same in each case, a description of the operation of the transmitter will be sufficient.

219. Referring to the diagram, the key *Tk* in the circuit of the transmitter is open and the magnet cores are energized by the current in the circuit *a–n* to a strength of, say, one unit, which tends to move the tongue *c* against the contact *d* and thus connects either the + or − 130-volt dynamo D_3 or D_4 to the point *h*. If the key *Tk* is closed, the cores of the magnets will be energized by a current in the circuit *b–Tk–S–m* to a strength of two units, which, being exerted in an opposite direction, not only cancels the effect of the current set up in the circuit *a–n*, but it also causes the tongue *c* to be moved with a force of one unit over against the contact *e*. This connects either the + or − 375-volt



Line
PR
NR
h
Artificial Line.
d
c
e
Transmitter
330 Ohms.
n
150 Ohms.
m
S
a
Tk
b
375 Volts.
375 Volts.
130 Volts.
130 Volts.
D1
D2
D3
D4
+
−
+
−
Pole Changer.
p'
p
n
330 Ohms
150 Ohms.
m
S
a
Pk
D
40 Volts.

Fig. 74.

dynamo D_1 or D_2 to the point *h*. The instruments *p* and *p'*, similar in all respects to the transmitter, constitute a pole changer. They are both controlled by the one key *Pk* and operate as a single instrument to produce reversals of the current for one set of signals. The transmitter varies the strength of the current for another set of signals.

220. The inventor says that in any instrument depending on a retractile spring for the motion of its armature in one direction and on magnetic attraction for its motion in the other, the action is not the same in both directions. As the armature approaches its limiting stop toward which the spring is drawing it, the tension of the spring becomes less, and the armature travels faster in the first part of its journey than it does in the latter portion; while, as it approaches the poles of the magnet, the reverse is the case. In the polarized instrument the movement is the same in either direction.

A long duplex circuit worked through repeaters equipped with this style of instrument is said to have its efficiency increased by the possibility of a microscopical adjustment of the relay points of the opposite set, and it is claimed that the double winding of this transmitter neutralizes the spark due to self-induction. That is, the electromagnetic induction of one coil on a magnet is neutralized more or less by that of the other coil on the same magnet, thus reducing the sparking at the contact points of the keys. The inertia of the moving parts being small permits a rapid movement of the tongue from one stop to the other, which, no doubt, makes the interval of no current during reversals much smaller than is possible with the present dynamo pole changer.

HEALY QUADRUPLEX.

221. In Fig. 75 is shown the quadruplex system devised by Mr. C. L. Healy and known as the **Healy quadruplex.** It is used by the New York Quotation Company. The same principle is used as is found in those systems that have

already been explained; namely, the reversal of the polarity of the current for working the distant polar relay, and an increase and decrease in the strength of the current for operating the distant neutral relay. The arrangement of the apparatus is somewhat different, however.

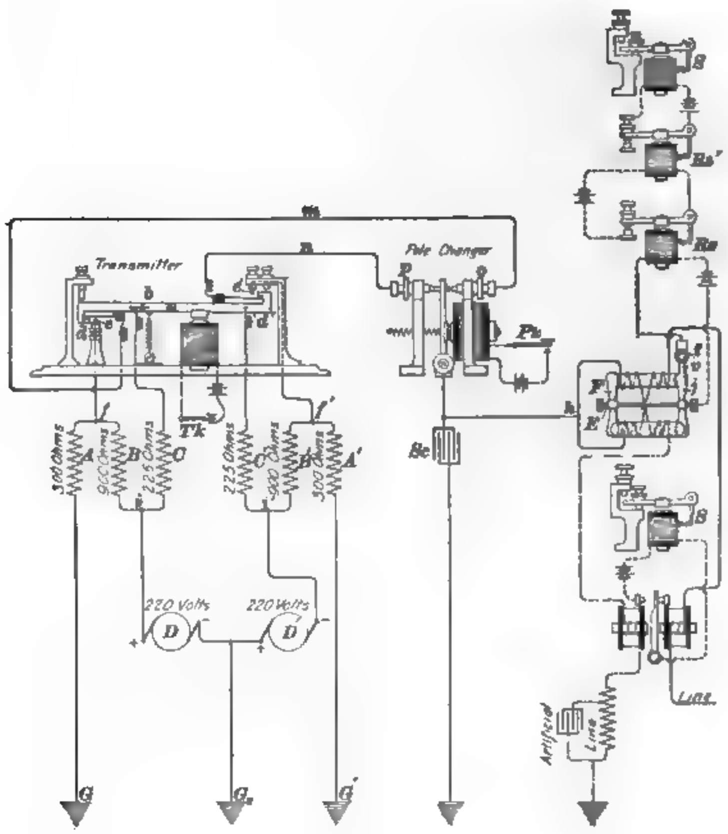


FIG. 75.

222. The transmitter consists, practically, of two ordinary continuity-preserving devices. The two levers are mechanically fastened together but are insulated from each other by the insulating material *b*; thus, one magnet really operates two transmitters of the ordinary form. When the

key *Tk* is closed, as shown in the figure, the wire *m* is connected with the end of the lever *d* and, hence, to the coil *C*; the wire *n* is connected with the end of the lever *d'* and, hence, to the coil *C'*. Consequently, when the key is closed, the positive pole of the dynamo *D* is connected through the resistance *C* to the end of lever *d* and wire *m* to the front stop *o* of the pole changer, and the negative pole of the dynamo *D'* is connected through the resistance *C'* to the end of the lever *d'*, and the wire *n* to the rear stop *p* of the pole changer. Thus the opposite poles of two similar dynamos are connected through exactly similar resistance coils, and through the transmitter to the front and rear stops of the pole changer. When the pole changer is closed, a positive machine will be connected to the point *h*; and when open, a negative machine will be connected to the same point *h*.

When the transmitter is open, the positive pole of the dynamo *D* will be connected through the resistance *B*, the point *f*, stop *e*, and wire *m* to the stop *o* of the pole changer; and the negative pole of the dynamo *D'* will be connected through the resistance *B'*, stop *e'*, and wire *n* to the stop *p* of the pole changer.

In the closed position of the transmitter, the current from the dynamo has two paths, one through the resistance *C* and the line to the ground at the distant station, and the other through the resistances *B* and *A* to the ground *G*. In the open position of the transmitter, no current can flow through the coil *C*, because it is open at *d*. The pole changer, by opening and closing, merely shifts the line and artificial-line circuits that come together at *h* from a machine of one polarity to that of the opposite; and the transmitter, by varying the arrangement of the resistances between the dynamo and pole changer, alters the strength of the current so as to give the ratio desired.

223. Resistance of Circuit Is Constant.—The resistance from the point *h*, through the pole changer, transmitter, resistance coils, and dynamo is the same in all

positions of the pole changer and transmitter. Evidently the position of the pole changer does not alter the resistance of this circuit in any way. The position of the transmitter itself alters the arrangement of the resistances, but does not alter the total resistance between h and the ground at the home station. The resistance from h through the transmitter to the ground will evidently be 225 ohms when the transmitter is closed, because the resistance from i to G_2 through the dynamo is perfectly negligible.

When the pole changer is closed and the transmitter is open, the point h is connected through the wire m and stop c to the point f, from which point it has two paths, one through the resistance A and the other through the resistance B and dynamo D to the ground. The joint resistance of these two coils since they are in parallel will be

$$\frac{300 \times 900}{300 + 900} = 225 \text{ ohms.}$$

It will be noticed that this is exactly equal to the resistance of the coil C; hence, the resistance from h through the transmitter to the ground is 225 ohms in either the open or closed position of the transmitter. Since the resistance from the ground through the transmitter to the point h is the same in both positions of the transmitter and pole changer, it follows that the total resistance of the circuit is the same in all possible combinations of the four transmitting keys, two at each end.

224. The **ratio of the current** in the line, between the open and closed position of the transmitter, may be calculated in the following manner, assuming that the line and artificial-line circuits each have a resistance of 1,800 ohms: In the closed position of the transmitter, the resistance in the circuit consists of the 225 ohms in the coil C, the 1,800 ohms in the line, and the 1,800 ohms in the artificial line. The line and artificial-line circuits are in parallel and, hence, their joint resistance is 900 ohms. This resistance added to 225 ohms gives 1,125 ohms; hence, the current in

the circuit under consideration, if each dynamo generates 220 volts, will be

$$\frac{220}{1,125} = .196 \text{ ampere, or } 196 \text{ milliamperes.}$$

Half of this current, that is, 98 milliamperes, will flow through the line and the same amount through the artificial line.

When the transmitter is open, the coil C will be on open circuit and the current from the dynamo will divide at the point f, part going toward the line and part through the coil A to the ground G. The resistance of the circuit from the point f to the ground now consists of three branches, one branch passing through A, one through the line, and one through the artificial line. The joint resistance of the line and artificial line is 900 ohms, as before, and this amount will be in parallel with the 300 ohms in the coil A; hence, the resistance from f to the ground through these three paths will be

$$\frac{900 \times 300}{900 + 300} = 225 \text{ ohms.}$$

This resistance is in series with the coil B that contains 900 ohms; hence, the total resistance of the circuit is $225 + 900 = 1,125$ ohms. The total current will be $220 \div 1,125 = .196$ ampere, or 196 milliamperes. This current will divide at the point f inversely as the resistance of the two paths; hence, we have the proportion 900 (joint resistance of the line and artificial line) is to $\frac{900 \times 300}{900 + 300} (= 225)$ as the total current flowing in both circuits, 196 milliamperes (which is the same as the current in the coil B), is to the current flowing toward the line from the point f. Hence the current flowing toward the line from the point f equals

$$\frac{225 \times 196}{900} = 49 \text{ milliamperes.}$$

One half of this current, or 24.5 milliamperes, will flow through the line and the other half through the artificial line.

When the transmitter is closed, the current in the line is 98 milliamperes; when open, the current is 24.5 milliamperes; from which fact it is evident that closing the transmitter increased the current in the line in the ratio of 1 to 4. In order to have the ratio 1 to 3 instead of 1 to 4, the resistances A and A' should be 400 ohms each; B and B', 800 ohms; and C and C', 267 ohms.

225. The **neutral relay** used in this system is different from any heretofore considered. The straight cores on which the coils are wound are made from very soft iron wire, as there are no yoke pieces; hence, the magnetism of the relays will reverse very rapidly on account of the low self-induction of the electromagnets due to the absence of iron yokes and the small quantity of good soft iron in the cores. The cores are about 2½ inches long and have a wire space of about 2 inches. Each core has two wires wound upon it, which form the two windings that go to make up a differential relay. It is preferable to wind these two wires upon the cores side by side, so that the differential action will be directly between adjacent turns, through which the current from the home generator circulates in opposite directions, rather than between the magnetism produced by such currents in the cores. In the figure, however, the two windings are represented, for the sake of clearness, as occupying separate longitudinal sections. Between and parallel with the cores is a brass shaft E that is held by centering screws at its ends. On the ends of the shaft E are secured two armatures F and j that move at right angles to the cores. These armatures are made light in weight, especially at the extreme ends, so as to reduce the inertia. The ends of the cores are beveled, and the two armatures, being of like shape, resemble the blades of a propeller. The armatures overlap the beveled ends of the cores and passing on opposite sides of the latter are simultaneously attracted or released by the cores; so that, being rigidly fastened to the brass shaft, they help each other. The armature j has an extension v working between two contact points and

connected with an adjustable retracting spring (that is not shown in the figure because it is at right angles to the paper).

The inventor of this relay claims that, since the wire space extends nearly over the whole length of the non-movable iron parts, there being no yoke over which wire cannot be wound, these magnets can be wound with larger wires, giving, nevertheless, a greater number of convolutions with the same or a greater resistance than it has heretofore been possible to obtain. Hence, the electromagnet should be more efficient than the ordinary relay. Furthermore, the core being short and there being no yokes, the reversals of magnetism take place very rapidly, and the time of no magnetism in the core, during the time that the reversals are taking place, is said to be reduced one-half.

226. Pole Changer.—The **pole changer,** although somewhat different in form, is really equivalent to the walking-beam type that has been already described. The arrangement of the contact stops, it is claimed, will enable a very close and positive adjustment to be made, so that the interruption of the current while the armature is shifting from one stop to the other lasts for a very small interval of time. A condenser *Sc* is connected between the lever of the pole changer and the ground to reduce the sparking between the lever and the stops *p* and *o*.

227. Sounders on Neutral Side.—In order, apparently, to avoid using the Smith arrangement of condenser and resistances, or the Jones induction-coil device, or the Edison system of one repeating sounder and one reading sounder, Mr. Healy devised the arrangement of two repeating sounders *Rs* and *Rs'* and one reading sounder *S*, which are connected as shown in Fig. 75. The repeating sounder *Rs* has its circuit closed when the neutral-relay armature rests against its *back stop t*. The second repeating sounder *Rs'* has its circuit closed when the armature of the first repeating sounder *Rs* rests on its front stop. The reading sounder *S* has its circuit closed when the armature of the second repeating sounder *Rs'* rests against its back stop.

By this arrangement it is claimed that the time necessary to cause any mutilation of the received signals is doubled and that, in practice, this arrangement has been found to greatly increase the working margin of the neutral side.

ROBERSON QUADRUPLEX.

228. The **Roberson quadruplex** system, the invention of Mr. O. R. Roberson, uses alternating sine wave currents. At present this system is in use in the New York Office of the Western Union Telegraph Company. When properly handled, this quadruplex will work *four-cornered* (that is, four messages may be transmitted simultaneously) better in extremely wet weather and on a smaller wire than will most of the other quadruplex systems. The principal objections to its use are the necessity of expert handling and the reluctance of telegraph companies to adopt a system employing alternating currents. The inductive effect on adjacent circuits makes the chief operators very backward, but without any real good reason, in advocating its adoption.

229. In this system, one message is transmitted by positive and the other by negative pulses, although there is sent to line at all times a series of weak alternating currents. On short lines, signals may be transmitted by merely sending a series of positive or negative pulses, according to which key is depressed; but on longer lines, signals are sent by increasing the strength of one polarity or the other, or of both, of the current normally flowing to line—that is to say, the positive pulses are strengthened by depressing one key, while the negative pulses are strengthened by depressing the other. Thus with both keys open, only weak alternating pulses are sent to line, while on their depression, strong positive, or strong negative, or strong pulses of both polarities are transmitted as one or the other or both of the keys are depressed. There is employed at each station an alternating-current dynamo provided with suitable collector rings and connections for sending to line positive and negative

pulses for the two sets of signals, and further means are provided for normally feeding weak, alternating pulses, at a frequency of about 40 periods per second, into the main line, and for sending positive and negative currents of increased strength into the main line on the depression of one or the other or both of the keys, as above outlined.

230. Fig. 76 (*a*) represents waves of positive pulses that are transmitted for the purpose of closing one relay at the receiving station. Fig. 76 (*b*) represents waves of negative pulses that close the second relay at the receiving station, while Fig. 76 (*c*) represents waves of both positive and negative pulses for simultaneously closing both relays at the receiving station.

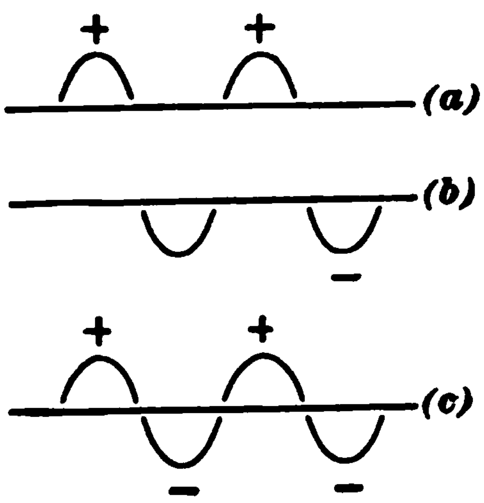


FIG. 76.

231. Fig. 77 represents the current generator and the transmitting and receiving apparatus at one station. One terminal of the armature winding *a* of the alternating-current generator is connected to a ring *b*, which is insulated from the shaft *e* of the dynamo; the other terminal of the armature is connected to segment *1*. The segments *1*, *2*, *3*, and *4* constitute a hub that is rigidly fastened to, but insulated from, the shaft *e*. On the periphery of the hub rest two brushes *i* and *j* connected, respectively, with conductors *11* and *13*. As shown in the figure, one armature terminal is connected through the segment *1* and the brush *i* with wire *11*, while the segment *3*, which is insulated from segment *1*, is connected through the brush *j* with the wire *13*. The segments *2* and *4*, which are insulated from *1* and *3*, are always connected together and with the hub *b* by the wire *8*, and thence to earth by the wire *10*. Also, on the shaft *e* is placed another hub, composed of segments *5* and *6*, segment *6* being permanently connected by conductor *9* through the hub *b* to the ground, while segment *5* affords an insulated terminal either for wire *12* or *14*, according to its position. By means

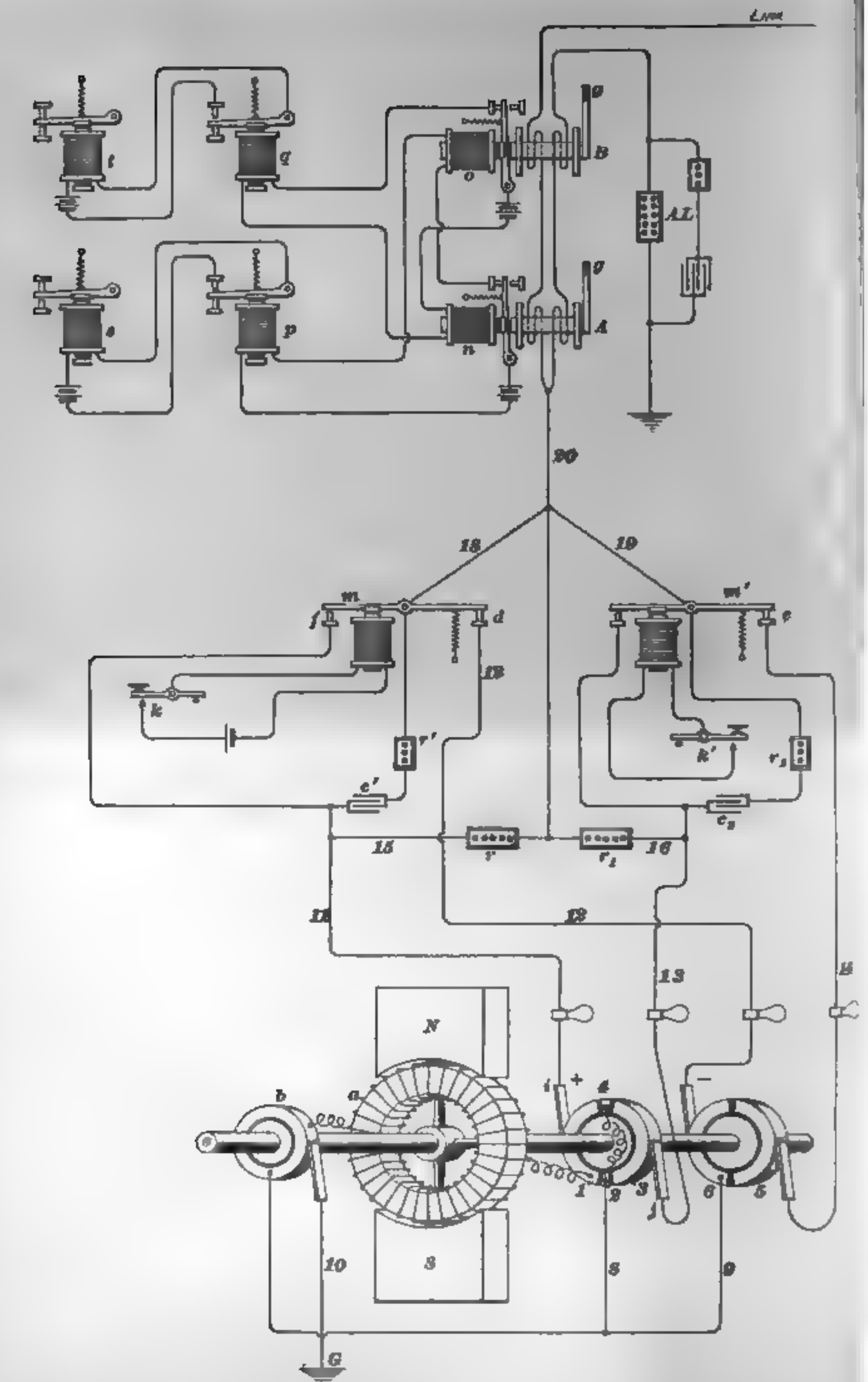

Line
g
B
t
q
o
AL
g
s
p
n
A
20
18
19
m
f
d
m'
e
k
r'
12
k'
r₁
c'
c₂
15
r
r₁
16
11
12
13
N
+
4
a
b
i
1
2
3
6
5
10
S
8
9
G

Fig. 77.

of the hub *5–6*, therefore, a ground connection is afforded from the main line for currents received from a distant station, either through wire *12* or *14*. When, as in the position shown in the figure, the wire *12* is connected through a brush with segment *6*, the main line is connected through the wire *18*, to back contact *d*, wire *12*, segment *6*, wire *9*, hub *b*, and wire *10* to the ground *G*. After a half rotation of the dynamo armature, however, and when segment *6* is in contact with the brush to which wire *14* is joined, the main line is given a ground connection through wire *19*, back contact *c*, wire *14*, segment *6*, wire *9*, hub *b*, and wire *10*. On closing the key *k*, connection between the armature lever *m* and conductor *12* will be broken; but in this case, in one position of the dynamo armature, a ground connection will be afforded by way of wire *18*, the front contact *f*, wire *11*, segment *1*, the dynamo armature *a*, hub *b*, and wire *10*, and at another position, when wire *11* touches either segment *4* or *2*, there will be a ground connection through wire *8*, hub *b*, and wire *10*. During that part of the rotation when the brush *i* rests on segment *3*, there will be no connection between wire *11* and the ground, because segment *3* is insulated, but a path to ground will be afforded, as before, through wire *14*, segment *6*, and conductors *9* and *10* to the ground *G*. Thus while the dynamo armature is making a certain half revolution, the front stop and back stop of one transmitter are both connected to ground, one by way of the armature, the other directly. At the same time, the front stop and back stop of the other transmitter are both disconnected entirely from the ground. During the next half revolution, however, these connections are all reversed. Thus one transmitter has control of the strength of the pulses while positive pulses are being generated, and the other while negative pulses are being generated.

232. When the key *k* is depressed, positive pulses, like those shown in Fig. 76 (*a*), will be transmitted from the dynamo through segment *1*, brush *i*, wire *11*, front stop *f*, armature lever *m*, and conductors *18* and *20*. The length

of the pulses will be somewhat less than a full positive wave, depending on the width of segments *4* and *2* and their surrounding insulating material. When segment *1* is in contact with brush *i*, the pulse generated is transmitted to the line; but when the shorter segments *2* and *4* are brought into contact with brush *i*, the line will be disconnected from the dynamo and grounded, thus affording the line an opportunity to discharge. Furthermore, the armature *a*, when in contact with brush *i*, is disconnected from brush *j* and wire *13*, so that while wire *11* is receiving a positive pulse no current will flow out over wire *13*. At the next half rotation, however, segment *1* is brought into contact with the brush *j*, and a negative pulse, which is then being generated in the armature, will be transmitted through wire *13*. Thus, as the armature rotates, wires *11* and *13* are alternately connected with the armature of the dynamo, and are fed alternately, the former with positive and the latter with negative pulses, while the main line at the termination of each positive and negative pulse is disconnected from the dynamo and is connected to earth to permit it to discharge.

The wires *11* and *13*, while ready to receive pulses from the dynamo, will not be fed with full currents except when the armature levers *m* and *m'* touch their front contacts. If both *k* and *k'* are depressed at the same time, the two conductors *11* and *13* will receive strong positive and negative pulses, as above described. These branches, however, will receive considerable current, regardless of the position of the levers *m* and *m'*, from the fact that connections to the main line are provided by the wires *15* and *16*, the particular purpose of which will be more fully described presently.

233. Receiving Apparatus. — The two relays *A* and *B*, are each provided with permanent horseshoe magnets *g*, soft-iron cores, and coils *h*, as shown in Fig. 78. It may be assumed that relay *A* at the distant station is closed by the depression of key *k* at the transmitting station, and *B* by the depression of key *k'*. The cores and permanent magnets are so arranged that the positive pulses sent to line on

the depression of the key at the distant station corresponding to k will add to the permanent magnetism of A and will neutralize or diminish that of B, while by the depression of the key at the distant station corresponding to k', the permanent magnetism of A will be diminished and that of B increased. By this means, the depression of key k at the transmitting end will attract the armature of relay A at the receiving station, while the armature of B will be attracted on the depression of key k'. Also, on the simultaneous depression of both keys k and k' and the transmission of successive positive and negative pulses over the main line, the armature of relays A and B at the receiving end will both be attracted to a signaling position.

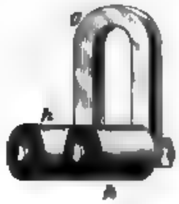


FIG. 78.

But it is to be noted that on the simultaneous transmission of positive and negative pulses, positive pulses will not act on the positive relay nor negative pulses on the negative relay as they would if only positive pulses or only negative pulses were being transmitted, from the fact that a rapid succession of positive and negative pulses through the coils of an electromagnet will tend to produce a neutral, or nonmagnetic, effect; whereas, positive or negative pulses alone will each produce strong magnetic actions. To overcome this difficulty, auxiliary electromagnets n and o, the branch circuits *15* and *16*, and the rheostats r and r_1 are necessary on long circuits, although in the case of shorter lines the branches *15* and *16* may be omitted. In the New York office, two carbon rods of 6,000 ohms resistance each are used in place of the rheostats r and r_1.

234. Operation.—If positive pulses only are received from a distant station, the armature of relay A will be attracted, thus breaking the local circuit, including the electromagnet o, but the local circuit, including the electromagnet n, will remain closed and will still exert a retracting pull on the armature of A. That is to say, if only positive pulses are received from the distant station, the pull of A

on its armature is sufficient to overcome the pull of the opposing electromagnet *n* and the spring. Likewise, if only negative pulses are received from the distant station, the pull of *B* on its armature is sufficient to overcome the pull of *o*, as has just been described in respect to the armature of *A* under the influence of positive pulses alone. Thus on the transmission of only positive pulses for one message, or of only negative pulses for the second message, the armature of *A* or *B*, respectively, will be attracted by their retracting magnets *n* or *o*, respectively, but with insufficient force to hold the local circuits closed.

If, however, both positive and negative pulses, like those shown in Fig. 76 (*c*), are transmitted from a distant station, the armatures of *A* and *B* will both be attracted and the circuits of both *o* and *n* will be broken, thereby leaving the armature subject only to the influence of *A* and *B*. In this case, the magnetism of *A* and *B* is much weaker than if the relays were subject to pulses of only one polarity, but while weaker, these relays are still able to pull their armatures with a force almost equal to that which they would have under the influence of pulses of only one polarity, with the local circuits through the retracting magnets *n* and *o* closed.

To still further equalize the actions of relays *A* and *B* under the influence of pulses of one or of both polarities, the branches *15* and *16*, with the rheostats r and r_1, are provided. By this means positive and negative currents will at all times be transmitted, although of much less strength than are those due to closing one or both keys. Also, pulses from the dynamo will be constantly directed to the line, but owing to the resistances r and r_1 they will be of comparatively small strength. These weakened pulses, when received from a distant station, will flow through the main-line coils of *A* and *B* and will produce an effect tending to neutralize the effects of stronger currents of one polarity. For example, if at the distant station the key *k* is depressed, strong positive pulses will flow through the main-line coil of relay *A*. At the same time, however, owing to the presence of the rheostat r_1 in the branch *16* at the distant station,

weakened negative pulses will be received in alternate order, thereby tending to neutralize, in a degree, the magnetism produced by the stronger positive pulses. Thus, not only is the armature of the relay *A* under a retractive force from the magnet *n*, but the magnetism that would be produced in *A* by the strong positive pulses will be considerably reduced by the weakened negative pulses. By both of these agencies, the armature of *A* will be under substantially the same tendency to move toward the front contact as when strong positive and negative pulses are alternately transmitted.

235. In Fig. 77, *A L* represents the ordinary artificial line of a duplex or quadruplex system, while at the left are represented repeating sounders *p* and *q* and reading sounders *s* and *t*, such as are used in some quadruplex systems where the main-line relays close their local circuits on the back contacts. Branches, including condensers and rheostats, are placed around the front contacts of the transmitters and serve to dissipate sparks arising at such points. The branch around the front contact of *m* includes condenser c' and the rheostat r', while the branch around the front contact of m' includes the condenser c_2 and the rheostat r_2. It may also be noted that the presence of branches *15* and *16*, including the resistances *r* and r_1, respectively, serve a similar purpose. The local receiving circuits may be arranged so that no intermediate repeating sounders are necessary and the grounded segments *2* and *4* may be omitted. This arrangement is shown in "The Telegraph Age," April 1, 1901.

236. The apparatus may be arranged on the bridge plan instead of as a differential system. In case this is done, the relays *A* and *B* will have only one winding, instead of a differential winding; they will be connected in the cross-branch of a bridge, the arms of which consist of the main line, the artificial line, and two more arms, each of which contains a resistance. The arrangement will be similar to that shown in Fig. 47. The resistance will be so

adjusted as to compel the current from the home transmitting apparatus to divide between the line and artificial line in such a ratio as to produce no difference of potential at the terminals of the cross-branch that contains the two relays *A* and *B*. The transmitting apparatus will be exactly the same as shown in Fig. 77.

BALANCING THE QUADRUPLEX.

237. Theoretically, a quadruplex balanced in identically the same manner as is the polar duplex should suffice for both the first and second sides; and, in fact, too great a proportion of those detailed to look after the apparatus consider their work finished when such a balance has been obtained. In practice, however, this is not sufficient to obtain the maximum efficiency. Even the careful adjustment of the No. 2 relay afterwards, although helpful, must necessarily be experimental and cannot be depended on.

NOTE.—These remarks, this method for balancing the quadruplex, and the suggestions on locating and remedying quadruplex disturbances, were given in various numbers of "The Telegraph Age" by Mr. Willis H. Jones.

There is something that interferes with the evenness of the incoming signals produced by the distant battery, aside from the period of "no magnetism" heretofore explained, and that something is an excess of magnetism in one coil of the neutral relay over and above that in the other. Now, if all relays were perfect, both in proper ohmic resistance and magnetic density, there would be little trouble, but, unfortunately, they are not. When new they pass a regulation test and give satisfactory results, but, like all devices, they are liable to deteriorate more or less. A stroke of lightning or an accidental excess of heat may burn the silk insulation around the copper winding and cause a few of the convolutions to be cut out in one coil. The damage may be very small, but it will cause a proportionate inequality in the density of the magnetic lines of

force set up in the iron core by the two currents from the home battery, although flowing with equal strength in both the main-line and artificial-line coils. In other words, if an ammeter showed that the strength of the current flowing in each coil of the relay was of identically the same value, the magnetism in the relay, produced by the current in the slightly defective coil, would be somewhat less than that in its side partner, because there would be a less number of convolutions of wire. Hence, the excess of magnetic energy in the stronger coil would antagonize the incoming signals. This antagonism must not occur. When the statement is made that the current should flow equally through each coil, it really means that the magnetic energy in the two coils must be of identical value.

238. If you balance a quadruplex possessing, say, a slightly defective polar relay and a perfect neutral relay, in the manner stated, the result will be that in order to magnetically equate for the polar relay, more current must traverse the weaker coil than passes through the other. This inequality of current strength can only be obtained by a corresponding difference in ohmic resistance of the main and artificial lines. Hence, if the current is adjusted until this polar relay is unaffected by the operation of the home pole changer, the balance so obtained will necessarily be false. If false, the evenly wound neutral relay will receive more current through one coil than through the other, as its coils are in the same path as the polar-relay coils, and are fed by the same currents. As the same rule applies equally to both relays, the excess of current strength in one coil of an imperfect relay will interfere with the incoming signals in the perfect relay.

It must not be supposed, however, that the defective polar relay described is to be met with very frequently, but there are so many combinations continually arising on the various circuits, that a practically similar state of affairs actually exists in a greater or less degree. But whether such conditions arise or not, the neutral relay is the weaker

instrument, and attention should be devoted entirely to it, even at the expense of the polar side, if necessary, as the latter instrument can dispense with considerable of its working margin without material injury. To attain the highest degree of efficiency, therefore, the following plan for balancing a quadruplex is given.

JONES'S METHOD.

239. Center Armature of Polar Relay.—*First*, ask the distant office to ground. This is done in Fig. 59 by turning to the right the arm of the switch *U*, in Fig. 63 the arm *u* of switch *M*, in Fig. 66 the arm *x* of the switch *M*, and in Fig. 70 the arm of the switch *Q*. After you have done likewise at your home station, center the armature of the polar relay in the manner explained in connection with the polar duplex.

240. Resistance Balance by Polar Relay.—*Second*, cut in your home battery by turning the switches mentioned in Art. **239** to the left, and, by adjusting the artificial-line rheostat *Rh*, balance in the usual manner. To do this, first close your transmitter and then adjust the rheostat in the open and closed positions of your pole changer until the armature of your polar relay will remain on either side.

241. Resistance Balance by Neutral Relay.—*Third*, with the switches mentioned in the preceding articles still turned to the left, that is, with the batteries "cut in," close your key on the second, or neutral, side and tell the distant office to cut in and dot on his second, or neutral, side only.

Pay no attention to the polar side, but consider your No. 2 relay and the pole changer an ordinary Stearns duplex set and proceed to balance as if you were handling that apparatus. In other words, while the distant office is "dotting" for you on the neutral side only, turn the retractile spring of the neutral relay down; that is, weaken the spring so as

to make it as sensitive to interference from your own home battery as possible, and yet respond to the dots made at the distant station. Then proceed to adjust the rheostat until you can close and open the key controlling your pole changer without its having the slightest influence on incoming signals.

242. Static Balance.—*Fourth*, to eliminate the kick due to the electrostatic capacity of the line, commonly termed the "static," ask the distant office to close his key on the polar side only, keeping his neutral, or No. 2, side open, the home key on the neutral side being closed. This places the local contact points on each home relay in their most sensitive position. Then, as before, turn down the retractile spring until the tension is very slight, and devoting your attention to the neutral relay alone, adjust the condensers and retarding coils until the home reversals fail to produce a kick. Since most of the static discharge is usually from that portion of the line nearest the home office, the condenser that discharges through one resistance should have about twice the capacity of the other. Adjust the condenser as well as you can, that is; until one plug gives too great a discharge and the next one too little, and then adjust the resistances in the retarding coils until the desired static balance is obtained.

243. To Adjust Neutral Relay.—*Fifth*, ask the distant office to write for you on the neutral, or No. 2, side while he dots on the other; then adjust the retractile spring of the neutral relay to the signals as you would if it were an ordinary relay. While adjusting, your transmitter key should be closed and the neutral relay should be adjusted until the distant signals are clear. When you reverse your pole changer, reverse it slowly at first, in order to make sure that the signals come equally clear under each reversal, then reverse it rapidly by dotting rapidly. Since dots often come clearly when words will not, it is better to test the signals coming from the distant office from the writing rather than from the dots made by the distant operator.

244. The preceding method of balancing a quadruplex system, in addition, of course, to the proper adjustment of the pole changer, has been more or less followed by quadruplex experts for years and the superiority of such a balance has been shown by its success. Since the kicks, when obtaining the static balance, invariably disappear from the polar relay first, it follows conclusively that the polar relay must not be depended on to tell when a perfect balance has been obtained. After having followed the instructions up to this point, it is time to turn your attention to the apparatus at the other end of the wire. This statement may surprise some, but it is a fact, nevertheless, that it is the duty of the home office to determine and to notify the distant office when his transmitting apparatus is not properly adjusted and when his battery is out of order.

245. Adjustment of the Dynamo Pole Changer.—The proper way to adjust a dynamo pole changer was explained in Art. **123,** in connection with the polar duplex. That article should be thoroughly understood by the student before he studies this one, which applies to the further adjustment and testing of the pole changer when it is used on a quadruplex system.

When the pole changer has been adjusted so as to have a minimum play, and at the same time gives low but distinct signals, the tendency to arc is reduced to a minimum. The receiving operator on the neutral side of the quadruplex at the distant office will then find that his relay is getting the maximum increase in current for a working margin. If the contact points of the walking-beam pole changer are too far apart, the duration of "no current to the line" will be so great that the neutral relay of the quadruplex set at the distant office will have time to partially demagnetize. As a result, it will allow its armature lever to be pulled from the contact point by the spring at the very time, perhaps, that it is making a signal, thus mutilating it.

Suppose that an operator at the home station believes that the distant pole changer is not properly adjusted; then he

should proceed in the following manner: He will first request the distant operator to close the key on the transmitter side of the desk, thus placing the home neutral-relay armature in position for making a dash. He will then ask the distant operator to dot on the key controlling the distant pole changer, the transmitter at the home station being kept closed. As soon as the home operator hears the dots on the polar side, he should turn his main-battery switch to the ground, in order to cut off all current except that from the distant station. Now, if the distant pole changer is improperly adjusted, there will be a kick on the home neutral relay every time that the key on the polar side at the distant office is manipulated, in spite of the fact that the signals may be received in good order on the polar side of the home station. If such is the case, the home operator should say to the distant operator: "Your reversals break up the second side." The home operator will pronounce the adjustment of the distant pole changer all right when the home neutral relay, or second side, is no longer improperly interfered with.

HANCOCK'S METHOD.

246. Another method of balancing a quadruplex system was described by Mr. B. P. Hancock in "The Telegraph Age." This plan, which we will call the **Hancock method,** is also based on a neutral-relay balance.

Not infrequently, after an apparently perfect balance has been obtained by the usual method, the polar relay having been used as a medium, it is found that when the distant office is cut in, the neutral side shows unmistakable signs of an imperfect equilibrium. This result may be due to inequalities between the windings of the polar or neutral relay, as has already been explained, or it may be that inductive currents are so much in evidence, and keep up such a rattle on the instruments under attention, that it is impossible to tell when a perfect balance has been reached.

Whatever the cause may be, some reliable method is needed to secure a practically true balance of the neutral side—the one object of marked solicitude at all times. The following method has given satisfactory results to Mr. Hancock and his associates for some time.

247. Center Armature of Polar Relay.—While the Hancock system makes use only of the neutral relay as the medium for obtaining the balance, it is best to begin by grounding the circuit at both ends and adjusting the polar relay until the armature rests indifferently on either stop or vibrates properly between them.

248. Resistance Balance.—In making a **resistance balance,** cut in your battery and adjust your rheostat until you have a line balance. Then have the distant office cut in by opening his neutral side and closing his polar side. Now take your own battery off the line by placing the arm of the ground switch on the grounded contact button, and turn the spring of the neutral relay down to the very lowest tension necessary to hold the armature in an open position, making certain that the magnets are sufficiently far from the armature to make only a slight tension necessary to produce that result. When this has been done, it will be found, when you restore your battery to the line and close the key on the neutral side, that if the balance is at all defective, your neutral relay will respond to the movement of your pole changer—closing when you open the pole changer and opening on the reversal, or *vice versa*.

To obtain a balance, place your pole changer in such a position that your neutral relay remains closed; gradually alter the resistance of your rheostat until, with the least change in resistance, the neutral-relay armature opens. The quickest way to reach this result is to remove the plug that will insert 1,000 ohms into the artificial-line circuit and note the effect on the neutral-relay armature. If it opens, replace this plug and unplug, say, 400 ohms. If now the relay does not open, remove another plug, adding, say, 100 ohms to the circuit; continue adding resistance until a

grinding movement appears in the neutral relay; then unplug about 10 ohms more, and you have the desired result.

Should the neutral relay fail to open when plugs are removed from the rheostat, proceed in the same manner, but insert the plugs instead of removing them. It is apparent that if the home battery does not manifest itself under these conditions it is not likely to do so at all.

249. Static Balance.—To find the **static balance,** turn the neutral-relay spring just high enough to keep the armature quiet when your keys are at rest; then adjust the condensers and retardation coils so that the neutral relay is not affected by your reversals. A perfect static balance is of the utmost importance if satisfactory results are to be obtained.

HOW TO LOCATE AND REMEDY QUADRUPLEX DISTURBANCES.

250. One of the most perplexing problems with which newly assigned chiefs and those detailed to oversee and care for quadruplex apparatus meet is, how to determine and locate a fault directly it is reported. To do this quickly and with any degree of certainty necessitates not only a thorough knowledge of both the mechanical construction and the theory of the apparatus, but a careful and persistent observation of each accompanying "symptom" as the various disturbances appear from time to time.

Nevertheless one must not be discouraged should the task of locating the disturbance by the observance of one or more of the numerous signs prove to be at fault. The most experienced experts are frequently compelled to make several tests before finally arriving at a definite conclusion, on account of the similarity of certain features accompanying faults of a widely different character. But as a rule, the most frequently occurring disturbances can be readily determined with a reasonable degree of certainty, after a

comparatively short experience, if one will but take the trouble to learn the significance of the ever-present guides, of which the following are the most trustworthy.

WIRE FAULTS.

251. Open Line.—If, while you manipulate the key on the No. 1 side of the desk, the *polar relay records your own signals* promptly and distinctly, even though you get the "back stroke," that is, even if the armature returns to its back stop when you release your key, and the removal or insertion of plugs in the rheostat has no disturbing effect on the signals, you may be certain that the *line wire is open.*

252. Crossed or Grounded Line.—Should the *signals be broken up*, however, or otherwise interfered with by the process, it will denote that the *line wire is closed*, but *that it probably is crossed or grounded at some unknown point.* If it is simply grounded, you will be able to center the armature of the polar relay when you turn the home switch to the earth, exactly as you would were this ground the legitimate compensating ground coil in the quadruplex apparatus at the distant office.

253. Foreign Current From Line. — Should the lever, under the above conditions, persist in clinging strongly to one pole of the magnet, it shows the presence of a current of electricity, which is probably from some foreign circuit with which the wire is crossed. Of course, it is possible that the current you get may be legitimate, and that the distant station, through defective or improper adjustment of the apparatus, may be unable to make you hear him; but where you have completely lost the office at the other end of the circuit, it is pretty safe to attribute the current to a cross.

254. To determine on which side of a repeating station the wire has failed, it is only necessary to listen to the

signals produced on your relay by manipulating your own key. If the fault is beyond the repeating station, the signals will be recorded on your relay and sounder a fraction of a second after your key makes contact. In other words, your own signals will apparently lag just behind the motion of your wrist.

DEFECTIVE APPARATUS.

255. It sometimes happens that while the wire "quads" O. K. at this end (to use familiar language), the distant office fails to get four corners out of his apparatus. It is in such cases that the skill of a chief operator is most severely tested, and when an opportunity is presented for him to help out of a difficulty an inexperienced quadruplex attendant at a small repeating station.

Let us assume, for the purpose of demonstration, that the wire and the apparatus at the other end of the circuit are O. K., but still the distant operator is unable to read our signals clearly on one or perhaps either of his relays. We will also assume that our apparatus is arranged for dynamos and that the trouble is in our own set.

256. The process to be followed would be to first ask the distant office to state the nature of the fault, in order that the search may be made in the right direction. If he says that the signals are distinct on his common side only when our polar side is quiet, it is more than likely that our pole changer is improperly adjusted. After we have cleaned the contact points and have adjusted them as closely as is possible, without giving them a tendency to spark, ask the distant office to ground and to listen to his own neutral relay while we manipulate our pole changer, while our full battery is connected in the line—that is, with our transmitter closed. If under these conditions the distant operator hears no click on his neutral relay, the fault will have been eliminated.

257. It frequently occurs that the distant operator cannot hear our signals on his neutral relay. When we are notified of this fact, we should immediately examine the tongue of our transmitter, as well as the wire attached to the "leak box" in the Western Union quadruplex. In nearly every case, the trouble will be found at one of these points. Perhaps the adjustment of the contact points is such as to prevent the tongue from being pulled away from the upper post when the transmitter is opened, thereby making no connection with the leak coil. Under these conditions, our full battery will continue to go to the line by way of the upper post of the transmitter, regardless of its position, and the neutral relay at the other end of the wire will, therefore, remain closed.

For a similar reason, the distant neutral relay will remain open, irrespective of the position of our transmitter, should the tongue of the latter cling to the lower contact point. In the latter disarrangement of the device, the 900-ohm leak coil in the Western Union quadruplex will always be connected, and, consequently, the electromotive force will be reduced to a strength equal to that of a short-end battery.

258. Defect in Leak-Coil Circuit.—Should the wire attached to the leak coil in the Western Union quadruplex become broken or disconnected, the neutral relay at the distant station will remain closed, regardless of the position of our transmitter, because the short route that reduces our electromotive force is now unavailable.

259. Defect in Ground-Coil Circuit. — Again, we will suppose that the station in difficulty informs us that, notwithstanding the fact that his balance is apparently all right, on attempting to work the apparatus, he finds that both of his relays are more or less interfered with by his own battery. One pole of his battery may cause the incoming signals to be either light or heavy, as the case may be, while the other pole may have the opposite effect—possibly shutting out altogether the incoming signals.

We should immediately suspect our own ground coil of

being the cause of the trouble. It is quite evident that the apparatus at the other end of the wire is out of balance, and it therefore follows that the abnormal resistance to which the rheostat had been adjusted, while our end was grounded, disappeared the moment that we turned our switch to battery again.

The explanation of that fact is that an open ground coil will compel the incoming current to find a ground through our rheostat or the leak coil, either of which contains a much greater resistance than does the proper compensating ground coil. The balance at the distant station will, therefore, be false, because, after we have cut in, the actual resistance of the circuit will be much less than the resistance in the artificial line at the distant station.

A loose connection of the wire that is connected to a ground coil, or an ink-covered disk on the rheostat, may add a resistance of several hundred ohms to the ground coil and thus destroy its usefulness. If the fault cannot be quickly repaired, the distant station should adjust his rheostat to the incoming signals on his neutral relay, while we dot or write for him on our transmitter only, in accordance with the method of balancing that has been given.

260. Defective Ground Wire.—If, after obtaining a correct balance at both the home and distant stations, the maximum current is very much less than it should be, it is probable that the ground wire from the dynamos or battery is loose at one or both ends, or that it is open at one end. If it is open at one end, the current is forced to reach the ground through the artificial line instead of through the ground wire, thus reducing the current to about one-half its strength, because the resistance in the path of the current to the ground is about double its normal value.

BATTERY FAULTS.

261. One Pole of Battery Open.—When the distant office, after taking a careful balance, informs us that he can hear our signals on his neutral relay only when our

key on the polar side is closed (or open, as the case may be), it is possible that one pole of our battery is open, or, at least, that the current is not passing through the pole changer.

The quickest way to verify this fact would be for us to push our switch so close to the ground bottom that the point of a lead pencil will make contact between them. Then, by alternately opening and closing the key controlling the pole changer, and while we are inserting the point of the pencil between the button and switch arm, a current of electricity will cause a spark to appear the instant that contact is made. The absence of the spark will show that none of the current reaches that point, while the position of the lever of the pole changer will indicate which polarity is missing.

262. Should it be impossible to restore the battery at once, it will still be possible to get a duplex out of the quadruplex apparatus. This may be done by so setting your key on the polar side that the lever of the pole changer will rest on the "good" pole of the battery. You may then utilize the common or neutral side as a duplex. Do not attempt, in this case, to transmit on one side of the quadruplex and receive on the other side, as inexperienced operators have frequently attempted to do, because the apparatus will not work since both sides cannot be properly balanced. You will simply destroy both sides by the operation.

263. Defective Cell.—Many of the troubles found in connection with quadruplex systems are due to loose connections, broken wires, defective batteries, punctured condensers, and defective resistance boxes, in addition to the bad condition of the various contact points. A defective cell in either the long-end or short-end battery is very often the cause of considerable trouble. If there is a defective cell in the long-end battery at the distant office, the fault will appear only when the distant office has his transmitter key closed. If the cell is so bad as to actually open the battery circuit, the polar relay will not be affected when the

distant pole changer is operated, as long as the distant transmitter is closed; and the operation of the distant transmitter will not operate the home neutral relay at all. On the other hand, should there be a defective cell in the short end of the distant battery, the trouble will appear in either position of the distant transmitter, and the current will be too weak to even operate the polar side.

264. Defective Tap Wire.—A break in the tap wire at the distant station will interrupt all current when the short end of the distant battery is connected to the line, as it should be when the transmitter is open. In this case, the polar relay will work all right when the distant pole changer is operated, provided the distant transmitter is closed. When the distant transmitter is open, neither side will work.

265. There are symptoms that, although pointing strongly in a certain direction, may possibly be due to an entirely different cause from the one suspected. For example, after having taken a careful balance and adjusted the apparatus for the best results, it is frequently found that, in spite of these efforts, the incoming signals on the neutral relay are still more or less interfered with as soon as the distant office begins to send on the polar side. This sign of trouble naturally points to an improper adjustment of the distant pole changer, and in a great majority of the cases, this will prove to be the disturbing element. In order to be certain that the home apparatus is not defective, it is well to exchange the set, temporarily, with another that is known to be in good condition. Should there still be no improvement and you are sure that the wire itself is perfectly clear, it will then be in order to suspect the distant battery.

266. Margin Too Small.—It is possible that the strength of the incoming current, due to the short end of the distant battery, too nearly approaches the strength of the current due to the long end of the distant battery. When such a condition exists, it is customary to notify the distant office that his proportions are incorrect, meaning, of

course, that the respective currents from his short-end and long-end batteries are not reaching us in the proper ratio of 4 to 1, or 3 to 1, as the case may be.

This discrepancy may arise from a variety of causes, but in nearly every instance (assuming that the wire is perfectly clear and free from escapes) the trouble will be found to be due to a defective or improperly adjusted transmitter, dirty contact points, a defective leak coil, or a loose connection of the wire attached to the leak coil at the distant station. Possibly one contact point of the distant pole changer is black from oxidation, thereby causing a higher resistance in one position of the pole changer than in the other.

It is quite evident that a dirty or improper contact between the tongue of the transmitter and the lever bar might add a resistance of hundreds of ohms to the route of the current. The effect of such a condition on the current in the Western Union quadruplex will be identical to increasing the resistance of the leak coil by just that many additional ohms. Under these conditions, the resistance of the 600-ohm lamp in the dynamo circuit plus the 1,800 ohms in the added resistance coil will be considerably less, in proportion to the resistance through the tongue and the leak coil, than it should be. Hence, a much larger proportion of the total current might be forced through the line to the distant relays than is intended. Therefore, an abnormal condition, through the chance resistance of a distributing element, may cause the strength of the current due to the short end of the battery to be very nearly equal in value to that due to the long end. A loose connection at the binding post of the leak coil will also increase its resistance and so increase the short-end current in the line in the same manner.

In verification of the above, it is only necessary to call attention to the fact that when it is desired to increase the short-end current under normal conditions, it is done by simply adding 100 ohms to the leak coil by removing the plug from the right-hand hole of the leak-and-added-resistance box, which contains that amount of surplus resistance to be used for this very purpose. The addition of a resistance

in the leak-coil circuit, therefore, increases the strength of the current from the short-end battery, but does not necessarily alter the value of the current from the long-end battery.

267. Improperly Adjusted Transmitter.—It quite frequently happens that the stronger current is greatly reduced in value, notwithstanding that the dynamo or battery may be furnishing full pressure. Under these conditions, the working margin of the neutral relay will appear to be very small. In all probability, the source of this small margin will be found in a double contact between the tongue of the transmitter and both the upper and the lower contact points, owing to an improper adjustment of the transmitter. Should the tongue accidentally touch the lever bar so imperfectly as to cause a high resistance at that point, during the time it should make contact only with the stop, a much smaller proportion of the total current will flow through the line and distant relays than was intended; hence, it may cause the strength of the current due to the long end of the battery to be very nearly as small as that due to the short end.

268. If, during wet weather, the system has been worked as a duplex only and an extra resistance *w*, Figs. 56 and 59, in the battery circuit was necessary in order not to have an excessive current, this resistance must be cut out when the wet weather clears and the system is to be used again as a quadruplex. If this resistance *w* is not cut out at the distant end, it will be found that the margin on the home neutral relay is very small. When it is suspected that the weakening of the incoming current, when the long end of the distant battery is connected to the line, is due to the fact that this resistance is still included in the circuit at the distant end, the distant operator should be requested to see that this resistance is cut out.

269. Experience Required.—It requires considerable actual experience to be able to nicely adjust the apparatus; but one of the safest guides to follow is to see that the contact points of all transmitting apparatus are as close

together as they will work without sparking, and give to the spring a tension that will not cause a jar as the armature rebounds. At the same time, see that the lever works freely in the trunnion without destroying the good contact. The down stroke of all armatures should be slightly stronger than the up stroke.

Above all things, see that the spring on the pole changer does not cause the lever to tremble, or vibrate, when released by the local magnet, and remember that the closer together you get the pole-changer points, the better will the man at the other end get your signals on his neutral relay.

MEASURING INCOMING CURRENT.

270. The most important thing to bear in mind in making tests of the incoming current is that no matter what value the ammeter, or current indicator, gives for the strength of the current from the long-end battery, the strength of the current due to the short end of the distant battery should be approximately just one-third or one-fourth that due to the long end, according to whether the distant station is giving you a proportion of 3 to 1 or 4 to 1. When an improper ratio between the incoming line currents in the open and closed positions of the distant transmitter is suspected, the manner in which the strength of the current from the distant battery may be measured, assuming, of course, that the wire itself is clear and free from abnormal escapes, is as follows.

271. Western Union Method.—If the current is to be measured at the desk of a Western Union quadruplex set, proceed in this manner:

1. Ask the distant office to close both keys.
2. Turn the home switch to the ground button.
3. Remove the main-line wire from the binding post of the polar relay (usually the binding post at the extreme right), and insert the wedge of the ammeter between the

line wire and the binding post, using finger pressure to make a firm connection.

4. Note the deflection of the needle of the ammeter, and record the reading as the value of the current from the distant long-end battery, that is, with the distant transmitter key closed.

5. Cut in the battery and say to the distant office: "Open the key on the polar side only." Then ground the wire again and proceed as before. The reading now shown by the needle of the ammeter will represent the strength of the current from the long-end battery, but due to the other pole of the battery, and should be practically the same as that due to the other polarity. Neutral quadruplex relays require from 45 to 60 milliamperes. Hence the strength of the current from the distant long-end batteries should give a value within these limits.

6. Cut in again and say: "Open the keys on both sides of the table." Then ground and measure as before. The needle will denote the value of the current from one pole of the distant short-end battery. The other polarity is measured in a like manner, after first requesting the distant office to close the key on the polar side only. These two measurements of the current from the distant short-end battery should also agree in value. Polar relays on quadruplex circuits require from 15 to 18 milliamperes for the value of the current from the distant short-end battery.

272. Postal Telegraph Method.—In order to measure the ratio between the strength of the incoming current in the open and closed positions of the distant transmitter in the Postal Telegraph arrangement of connections, insert the wedge, to which the milliammeter is connected, between the lever of the ground switch and the ground button. In Fig. 70, for instance, insert the milliammeter wedge between the arm of the switch *Q* and the ground button *v*. The current flowing through the milliammeter, when in this position, will be somewhat smaller than the current actually flowing in the line coils of the

relays; nevertheless, the milliammeter reading will be proportional to the strength of the current in the line coils, and, consequently, if the reading of the milliammeter is reduced one-third when the distant transmitter is opened, then the current in the line coils is also reduced to one-third its previous strength.

To test the home battery, have the distant office ground his end, and insert your milliammeter wedge between the lever of the ground switch *Q* and the battery button *u*, Fig. 70. Then, by opening and closing the transmitter key, the ammeter will indicate the difference between the current from the long-end and short-end batteries.

273. If the ratio between the electromotive forces, or the ratio between the added and leak resistances in the Western Union quadruplex, or the ratio between the resistance *A*, *B*, and *C* in the Healy quadruplex at the distant station are correct, the value of the long-end measurements (irrespective of battery polarity) should be represented by a figure practically either three or four times as great (depending on the ratio employed) as that obtained by the short-end measurement.

274. Galvanometer to Determine Condition of Circuit.—When the Kansas City office of the Postal Telegraph Company was equipped, a galvanometer was included in the multiplex circuits in order that the condition of each multiplex circuit between the home office and the other terminal, or repeater, station could be told at a glance, thus avoiding the necessity of trying a balance and, consequently, saving much time. If one coil of a differentially wound galvanometer be permanently connected in the line circuit and the other coil in the artificial-line circuit, it can easily and quickly be determined if the current from the home station divides equally between the two circuits mentioned and, also, if the ratio between the minimum and maximum current is the one desired.

275. Defective Condensers. — Sometimes the condensers in the artificial line will be punctured by a lightning

discharge during a thunderstorm. When this happens, the artificial line is short-circuited, and no amount of adjustment of the resistances or condensers will balance the line. The defective condenser must be replaced by a good one before a balance can be obtained.

DISTURBANCES DUE TO TROLLEY CURRENTS.

276. In some localities where trolley or electric-light plants are located, the potential of the earth frequently becomes so high through leakage or otherwise that if one end of a telegraph wire be buried in the earth at that point and grounded at a distant station, a current will flow through the conductor from the point of the highest potential to the normal ground at the other end of the circuit. Should such a condition exist, the office at the station possessing the normal ground would apparently find his apparatus out of balance. If the foreign electromotive force from the distant ground is, say, 10 volts positive, it will add that many volts pressure to the positive pole of the battery located at that point, and equally oppose 10 volts to the negative pole, actually causing a difference of 20 volts between the two polarities. The neutral relay at the station possessing the normal ground will therefore be more strongly magnetized by the incoming current from one pole of the battery than from the other. This will render impossible the adjustment of the retractile spring on the home neutral relay to suit the strength of both currents.

Now, in order to ascertain whether the inequality thus found in the two currents is due to the presence of an auxiliary electromotive force, ground the wire at each end of the circuit, thereby cutting off both batteries, and then measure the current with an ammeter. Should the ammeter show an undue deflection (still assuming the wire to be clear), you may properly attribute the source of the disturbance to the leakage of current from a trolley or

electric-light plant, which gives the earth at that point a certain electrical potential.

277. Remedy.—When this disturbance in potential between two stations is constant and permanent, the remedy is to insert a few cells of battery in the common ground wire running to the dynamo; or, in the case of the gravity battery quadruplex, between the ground (*G*, Fig. 59) and the pole changer. The value of the electromotive force of the inserted cells must be identical with that producing the earth current, and the direction, of course, should be in opposition to the disturbing element; that is to say, if a foreign current from the ground is being forced into the wire with a pressure of, say, 10 volts positive, 10 volts positive must be inserted against it in order to destroy its detrimental effect.

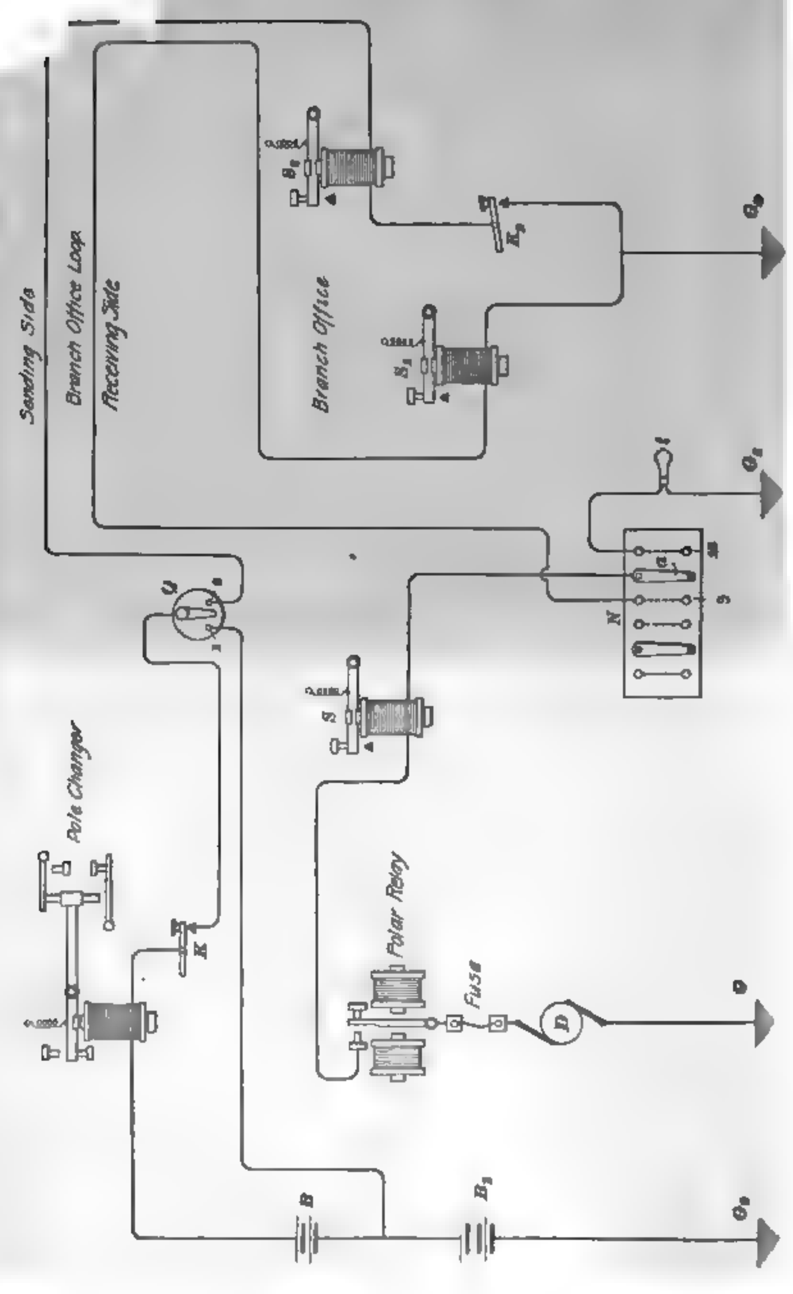
278. To Determine Number of Cells Required. To determine the number of cells to be inserted, ground the wire at both ends of the circuit and note the deflection of the needle of an ammeter connected in the line circuit. Then insert a few cells of battery in the common ground wire and again observe the deflection. If the strength of current, as shown by the ammeter, has been increased in value, it will indicate that the wrong end of the row of cells has been placed toward the line. Reverse their position, and measure as before. Continue inserting or subtracting cells until the needle returns to zero.

It is important that the cells used for this purpose should have little or no appreciable internal resistance, as an appreciable resistance would be equivalent to increasing the resistance of the dynamo or battery circuit, which would be wrong. A gravity battery, therefore, would not be desirable. A storage battery would be an ideal one for this purpose. As the value of the earth current must necessarily fluctuate more or less between the periods of wet and dry weather, it would be well to have a few cells of battery in reserve, which could be switched in or out of circuit as occasion required.

BRANCH OFFICES CONNECTED TO MULTIPLEX SETS.

279. It is often desirable to extend the receiving and sending sides of duplex and quadruplex circuits to a branch office. The general method of doing this where dynamos or primary cells are used is shown in Fig. 79. Where batteries are used, it is customary, in order to get the same current, to increase the number of cells when the circuit is extended to a branch office. The method of doing this is shown in connection with the pole changer in Fig. 79. When the arm of the switch Q rests upon the contact button *1*, the magnet of the pole changer is connected in series with the key K and the battery B. When the arm of the switch Q is placed on contact button *2*, the pole changer is placed in series with both batteries B and B_1, the sending side of the branch-office loop, the sounder S_2, and the key K_2 at the branch office. The circuit in this case is completed through the ground from G_3 to G_2.

Where dynamos are employed as shown in connection with the polar relay, it is not convenient to increase or decrease the electromotive force of the dynamo, and in order to keep the current the same, a resistance, usually a lamp l in Western Union offices, is placed in the circuit when it is not extended to the branch office. N is the usual form of switch used in connection with the local circuits of duplex and quadruplex sets where dynamos are employed. Only such connections of this switch are shown here as are necessary to explain the figure. When the arm a rests on contact button *10*, the dynamo D, contact points of the polar relay, the main-office sounder S and the lamp l are placed in series; the return circuit is through the ground from G_1 to G. When the switch arm a rests on contact button *9*, the branch-office receiving side, including the branch-office sounder S_1, is placed in circuit in place of the lamp l. The circuit may then be traced from the ground G through the dynamo D, contact points of the polar relay, the main-office sounder S, switch arm a, contact button *9*,


Sending Side
Branch Office Loop
Receiving Side
Branch Office
Pole Changer
Polar Relay
Fuse

the receiving side of the branch-office loop, the sounder S_1, and ground G_1 back to the ground G. Obviously, in order to have the same current through the sounder S in both positions of the switch arm a, the lamp l should have a resistance equal to that of the branch-office sounder S_1 and the line wire (receiving side) between the main and branch offices. In offices where dynamos are employed, there would be a main switch at which the line wire would terminate, and usually a loop switch at which the branch-office loop would terminate, but these switches have been omitted here for the sake of simplicity.

TELEGRAPHY.

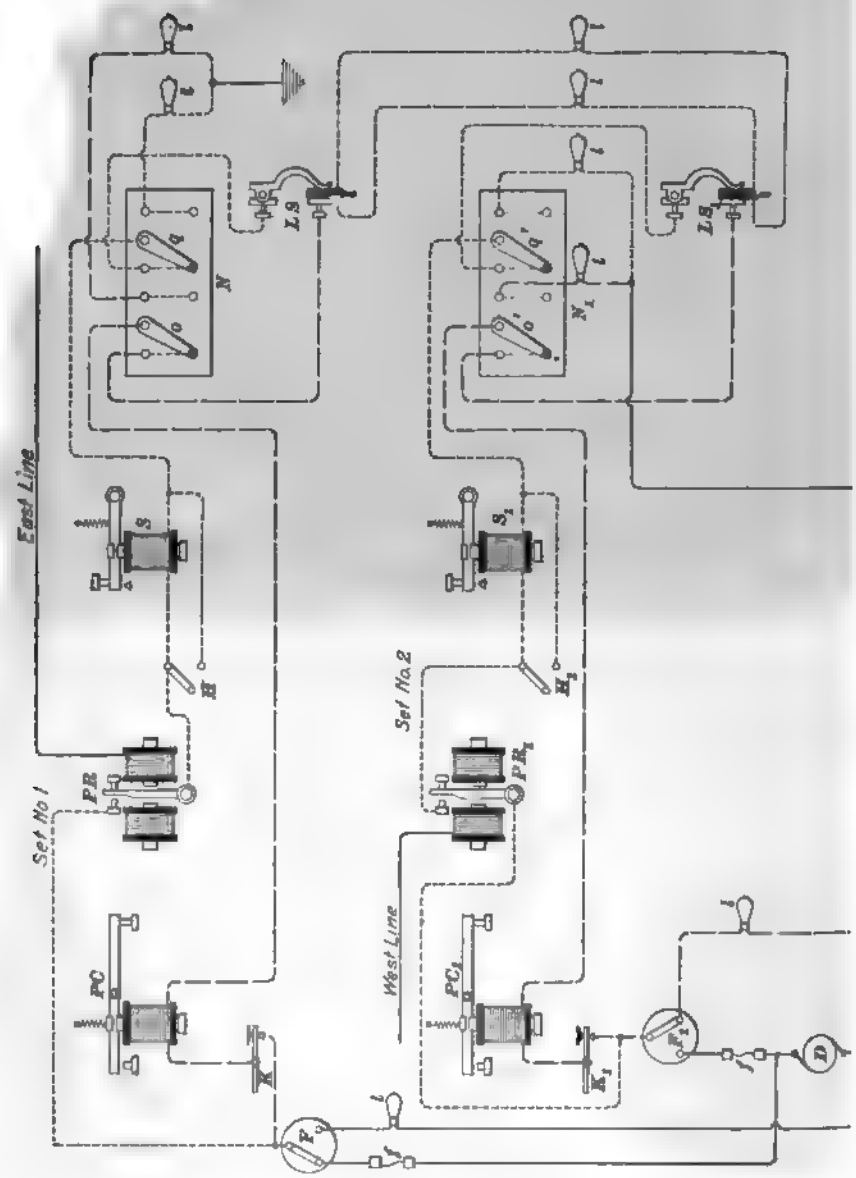
(PART 5.)

COMBINATIONS OF REPEATERS AND MULTIPLEX SETS.

MULTIPLEX REPEATERS.

POLAR DUPLEX REPEATERS.

1. Dynamo Arrangement.—It is a very simple matter to connect two duplex sets so that the receiving side of set No. 1 will repeat into the sending side of set No. 2, and the receiving side of set No. 2 into the sending side of set No. 1. Two duplex sets, arranged to repeat in this manner, are shown in Fig. 1. Each set is arranged as usual when dynamos are used to supply the current. The dynamo D (a 23-volt machine in Western Union offices) supplies current for all local circuits. With the switch arms o, q, o', q', and F turned to the left and F_1 to the right, the polar relay PR in set No. 1 controls the pole changer PC_1 in set No. 2, and the polar relay PR_1 in set No. 2 controls the pole changer PC in set No. 1. The two sets are connected together through the jacks and wedges LS and LS_1 at the loop switchboard. The receiving side of one set becomes the sending side of the other set; hence the dot lines are


East Line
West Line
Set No 1
Set No.2

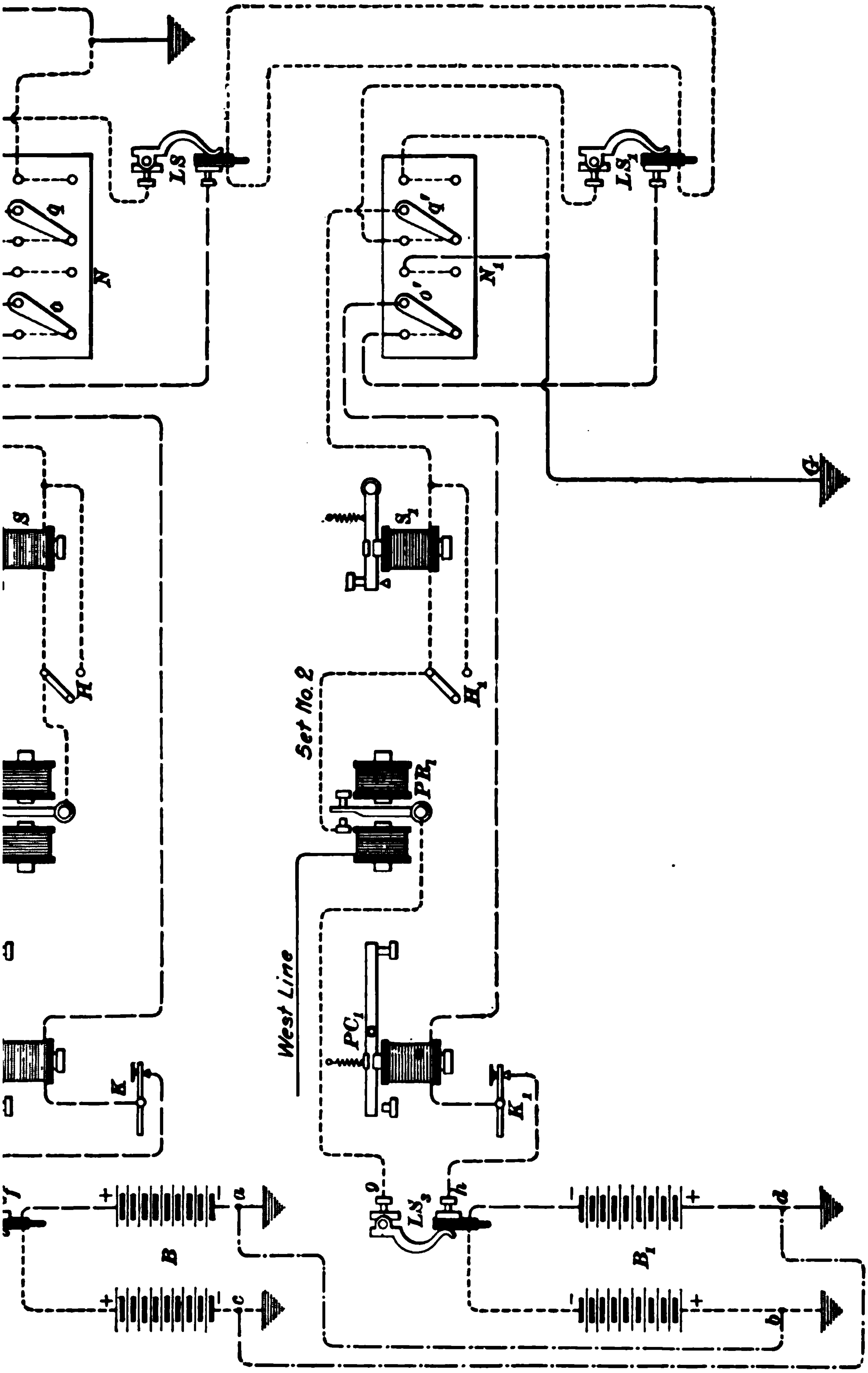

LS
N
q
o
S
H
K
B
a
c
LS1
N1
q'
o'
G
S1
H1
Set No. 2
PR1
West Line
PC1
K1
LS3
g
h
B1
d
b

FIG. 2.

changed to dash lines and the dash lines to dot lines at the lamps in the cord circuits between the two spring jacks LS and LS_1. The incoming signals from the east line operate the polar relay PR, and this in turn operates the pole changer PC_1; thus the signals coming in over the east line are repeated into the west line. Similarly, signals coming in over the west line are repeated into the east line.

When the two sets are in operation as a duplex repeater, there is no need of the sounders S and S_1. By closing the switches H and H_1, the sounders may be short-circuited. Thus their resistance may be cut out of the circuit and the current increased somewhat. Switches for this purpose are quite convenient, especially where gravity cells are used for local batteries. The two sets may be readily disconnected and arranged in two entirely independent sets, although supplied with current for the local circuits from the same dynamo D. To do this turn the switch arms o, q, o', and q' to the right and the switches F and F_1 to the left.

2. Battery Arrangement.—In offices where gravity batteries are used, the polar duplex may be arranged as shown in Fig. 2. The arrangement is exactly the same as in the preceding figure except that the wires e, f, g, and h run through jacks at the loop switchboard to gravity batteries, instead of through three-point switches on the desk to a dynamo, and no lamps are required. The lamps are not required because the correct number of cells are supposed to be used in the batteries B and B_1 to give the proper current. The batteries B and B_1 may be main-line batteries with one terminal of each grounded, or they may be intermediate batteries, in which case they would not be grounded, but would be connected as shown by the lines $a\,b$ and $c\,d$. In the former case care must be taken to connect the proper pole of each battery to the wedges, so that they shall not oppose one another. If one set of batteries, B, for instance, is strong enough, then both sides of the wedge in the jack LS_1 should be simply grounded or else connected with the negative poles of the batteries B at a and c. The switch

arms o, q, o', and q' are used in the same manner as explained in connection with the dynamo arrangement shown in Fig. 1.

QUADRUPLEX REPEATERS.

3. It is sometimes necessary on long circuits to repeat from one quadruplex set into another. This can readily be done by connecting the repeating sounder on the common side of the first set so that it will operate the transmitter of the second set, and the repeating sounder of the second set

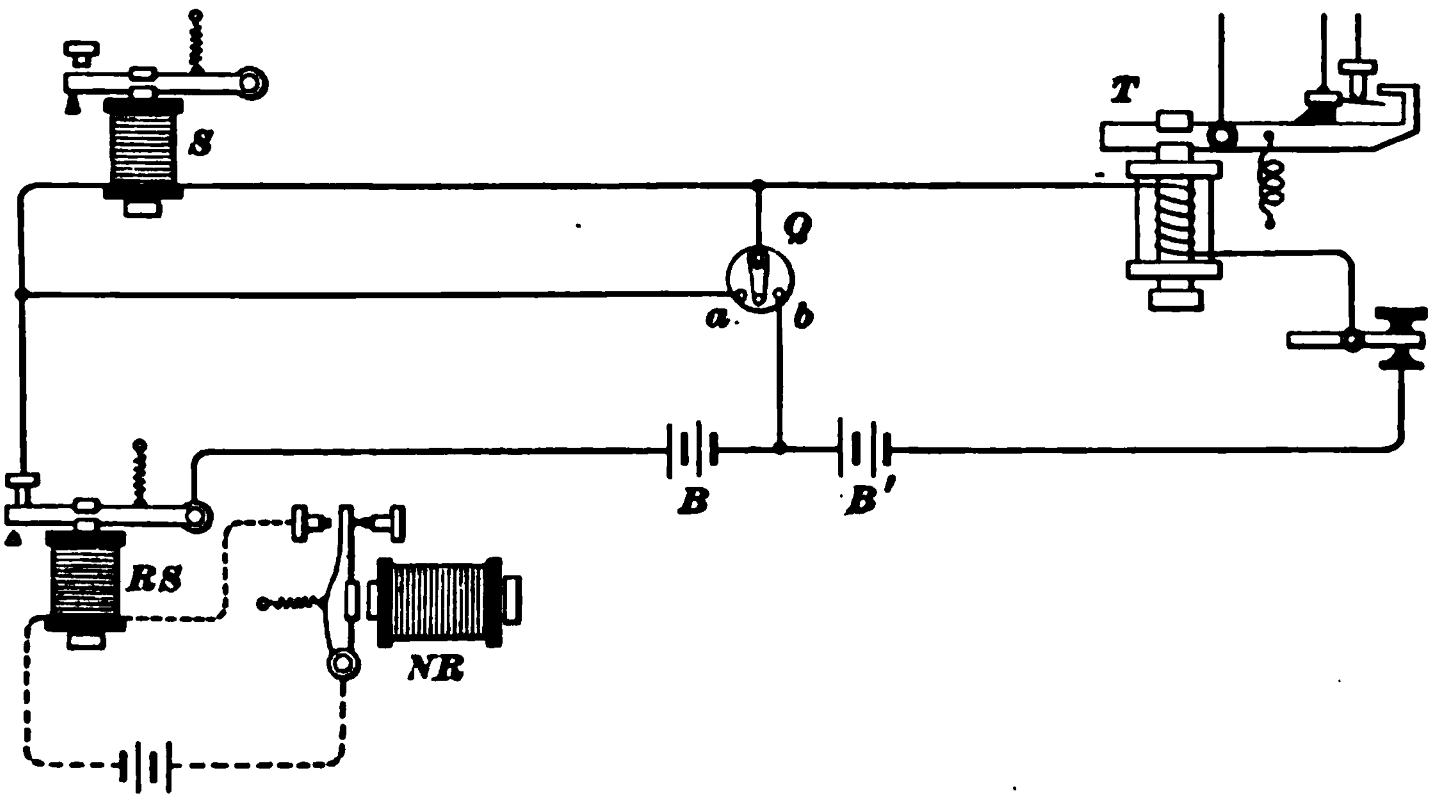
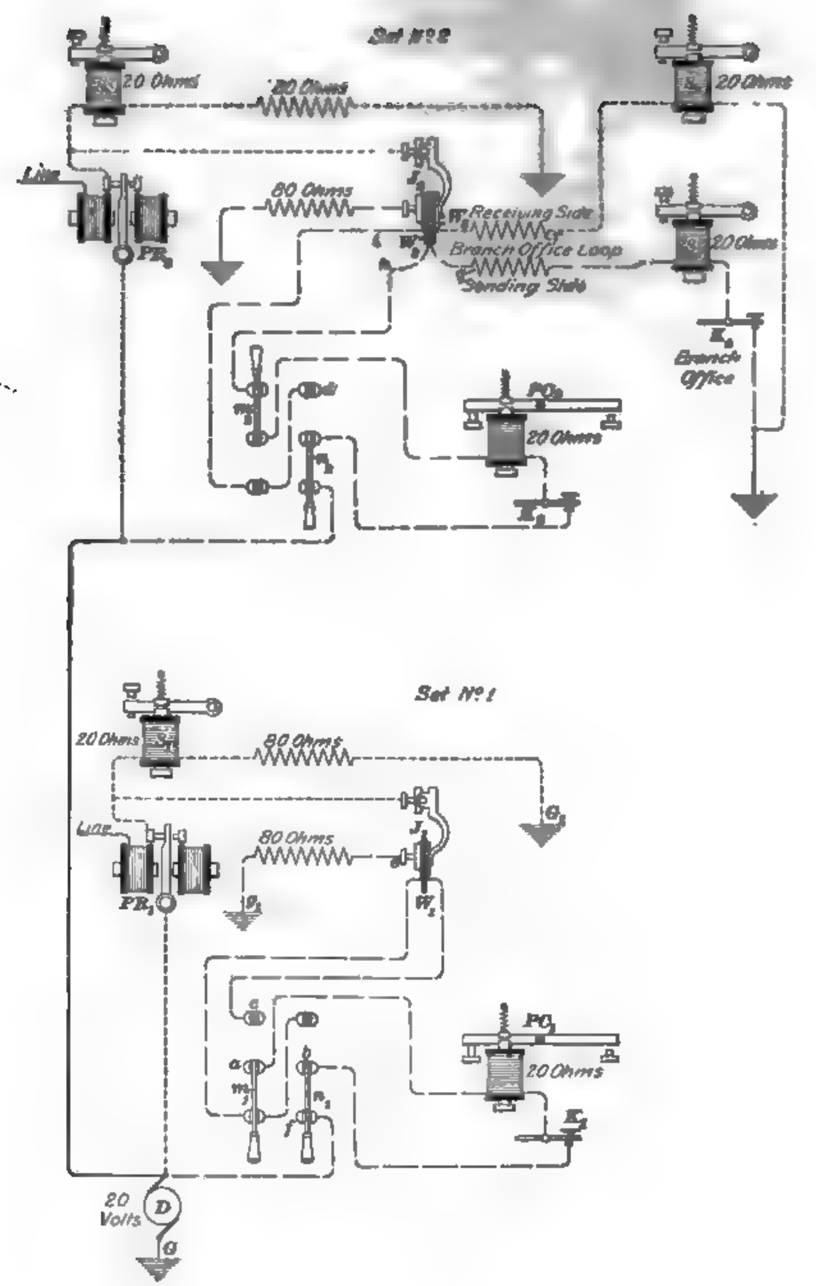


FIG. 3.

so that it will control the transmitter of the first set. On the polar sides, the polar relay of the first set controls the pole changer of the second set, and, conversely, the polar relay of the second set controls the pole changer of the first set.

If the wires are in good condition, it is immaterial whether the polar side of one set repeats into the polar or common side of the other set. If, however, conditions are such that the polar side of two quadruplex sets are working better than the common sides, then it might be better to repeat from the polar side of one set into the polar side of another, and from the common side of one into the common side



Set No. 2
20 Ohms
80 Ohms
20 Ohms
Line
80 Ohms
Receiving Side
Branch Office Loop
Sending Side
20 Ohms
Branch Office
20 Ohms
Set No. 1
20 Ohms
80 Ohms
Line
80 Ohms
20 Ohms
20 Volts

FIG. 4.

of the other. By doing this, one side is working in good condition, while the other side may be working in a more or less indifferent manner; then if necessary the poorer side may be abandoned and still leave the other side in workable condition. On the other hand, if the polar side of one set repeats into the common side of the second, and the polar side of the second repeats into the common side of the first, then both sides may work indifferently, if both common sides are not in first-class condition. The advantage of one or the other method will depend on how poor one side is working.

4. In Fig. 3 is shown the diagram of connections, where gravity batteries are used, whereby the repeating sounder *R S* of one set controls the transmitter *T* of another set. The switch *Q* is so connected that when the arm rests on contact button *b*, the two sets are working independently. When the arm of the switch *Q* is in the middle position, the two batteries are both in series with the transmitter *T* and the sounder *S*. This enables the attendant operator to read the signals by means of the sounder *S*. When the arm of the switch *Q* is placed on the contact button *a*, the two batteries *B* and *B'* are both connected in series with the transmitter *T* as before, but now the sounder *S* is short-circuited. If the current is too strong with the sounder *S* short-circuited, it may be left in the circuit.

The arrangement between the two sets on the polar side is so similar to this that it seems unnecessary to give it here.

ARRANGEMENT OF LOCAL CIRCUITS ON CANADIAN PACIFIC RAILROAD.

5. On the Canadian Pacific Railroad, the local sounders, pole changers, and transmitters are wound to a resistance of 20 ohms. They could all be connected in multiple to a 6-volt dynamo, but in nearly every office where dynamos are used, the local circuits of the multiplex sets are connected as shown in Fig. 4. Each half of a quadruplex set,

or half-repeater, is treated as a duplex set. By resistance coils each local circuit of the multiplex and repeater sets is brought up to 100 ohms resistance and the local-circuit dynamo gives from 20 to 25 volts, the former voltage being usually found to be sufficient.

The lower half of the figure shows one set as ordinarily arranged. Starting from the dynamo *D*, the receiving circuit passes through the contacts on the relay PR_1, 20-ohm sounder S_1, 80-ohm coil, ground G_1, and back through *G* to the dynamo *D*. A branch, or leg, passes through jack J_1, but is open at *c*. The sending circuit may be traced from the dynamo *D* through the switch n_1, key K_1, 20-ohm pole changer PC_1, switch m_1, wedge W_1, back contact *c* of the jack J_1, 80-ohm coil, ground g_1, and back to the dynamo *D*.

6. Local Circuit Extended to Branch Office.—To extend the local circuits of a duplex set to a branch office, the loop wedge W_4 is inserted in the spring jack on top of the wedge W_2, the switch m_2 is turned up and the switch n_2 down, as shown in the upper portion of the figure. The circuits are then as follows: Receiving side; dynamo *D*, polar relay PR_2, sounder S_2, 80-ohm coil, ground; also from the relay contact through the leg to the top of the jack J_2, front of the wedge W_2, coil *r*, receiving side of the branch-office loop, branch-office sounder S_3, and ground. The resistance coil *r* is adjusted so as to give the circuit a total resistance of 100 ohms from the wedge to the branch-office ground. Sending side; dynamo *D*, switch n_2, key K_2, pole changer PC_2, switch m_2, front of the wedge W_2, back of the wedge W_2, coil *q*, sending side of the branch-office loop, branch-office sounder S_4, key K_4, and ground. The resistance from the wedge to the branch-office ground is 80 ohms, including the sounder S_4. The resistance of the pole changer PC_2 is included in this circuit, thus making the total resistance 100 ohms, the same as on the receiving side.

7. One Set Repeating Into Another.—To work these sets as repeaters, the wedges of the two sets are exchanged, wedge W_1 of the No. 1 set being inserted in jack J_2, wedge W_2

in jack J_1, and the table switches m_1, m_2, n_1, and n_2 turned up. The circuit may then be traced from the ground G, through the dynamo, contacts of relay PR_1, sounder S_1 and 80-ohm coil to ground G_1; also from the relay contact to the top of the jack J_1, front of the wedge W_2, which is now supposed to be inserted in the jack J_1, wire h, switch m_2, pole changer PC_2, key K_2, switch n_2 to d, wire i, back of the wedge W_2, lower part e of jack J_1, 80-ohm coil, and ground g_1. The circuits from No. 2 set are the same. A break at the contacts of either relay will open its sounder and also the pole changer of the other set. Thus signals received from the line on No. 1 set are automatically transmitted over the line connected to No. 2 set, and *vice versa*.

8. In many places on Canadian Pacific lines, storage batteries are used in place of dynamos, in which case no resistances are inserted in the local circuits but extra cells are used, providing the necessary power when the quadruplex or duplex systems are extended to branch offices. When storage cells are used for main batteries, a switch, consisting of a series of spring jacks and wedges, is so designed that the jack is normally open and a wedge when reversed cannot be inserted. The negative pole of the battery is connected to the top of a wedge and the positive pole to the bottom. It is predicted that shortly storage cells will replace gravity batteries even for locals at wayside stations; the storage cells will be charged at some central point and distributed by train to the wayside stations.

MULTIPLEX SINGLE-WIRE REPEATERS.

9. It is often desirable to arrange a duplex or one side of a quadruplex system, in connection with a single wire running to another office, so that the message being received over the multiplex system may be sent over the single wire to the branch office, and so that the branch office may send through the multiplex apparatus at the nearer station to

the distant multiplex station. An arrangement of apparatus that will accomplish this is very convenient and often very necessary, and is known as a **multiplex single-wire repeater.** An arrangement of apparatus for accomplishing this same purpose in connection with city branch-office lines is known as a *defective-loop repeater.*

10. Defective-Loop Repeaters.—Large telegraph companies frequently rent out lines to brokers and others. Where only one wire is rented to a broker, it is sometimes desirable or necessary that the subscriber for this rented wire shall be connected to one side of a duplex or quadruplex set. The apparatus must then be arranged so that the party renting the wire can send or receive over the one wire. Furthermore, it sometimes happens that one side of a branch-office loop will be out of order or defective. It is then desirable to arrange the apparatus so that the branch office may send or receive over the remaining good leg of the branch-office loop. By arranging the apparatus so that this can be accomplished, much time is saved while the defective leg is being repaired. In either of the above cases, an arrangement to accomplish the desired purpose is usually designated as a **defective-loop repeater,** because it is so often used to utilize the good leg of a temporarily disabled branch-office loop.

The branch-office loop arranged in this manner cannot of course be worked double, that is, one message cannot be sent and another received simultaneously over the one wire; but a single wire, that is, one arranged so that messages can be sent either way, but not in both directions at the same time, is better than none at all, and as such it must be considered. A device of this kind should be kept at all main offices where loop circuits are connected with multiplex sets, for use in case of emergency.

11. To Prevent Repeating Back.—In all repeaters used in connection with multiplex systems, it is essential, of course, that means be provided to prevent the repeating back of a message to the original sending station. In

multiplex single-wire repeaters, this is usually accomplished by the application of the Toye-repeater principle, whereby a resistance is substituted in place of a branch-office circuit, when that circuit is opened; or by the Downer arrangement, whereby an extra battery is included in the higher resistance circuit; or by using half of almost any of the standard single-wire repeaters. The Downer, Moffat, and Half-Milliken repeaters may all be classed as defective-loop repeaters.

DOWNER REPEATER.

12. An arrangement of apparatus and circuits called the **Downer repeater** is shown in Fig. 5. The only additional apparatus not already required in the multiplex set is the repeating transmitter that is operated by the polar relay. The polar relay and the pole changer shown here belong to a regular duplex or quadruplex set.

13. Operation.—When the arm of the switch Q rests on the contact button *1*, the pole changer may be controlled, as usual, by an operator at the key K. In this position of the switch, the branch-office circuit is cut out. When the arm of the switch Q is placed on contact button *2*, the branch-office operator receives whatever messages come through the polar relay and repeating transmitter; or by manipulating his key K_2, he can send a message through the pole changer to the distant office—provided the polar relay is receiving no message and is closed. The operation of the polar relay opens and closes the branch-office line at the stop c, but, although it does open and close the branch-office line at this point, it does not open the circuit through the magnet of the pole changer, because the tongue b touches the lever a before it is pulled away from the stop c. Hence the pole changer is not operated. When the repeating transmitter is closed, the circuit may be traced from G through the batteries B and B_1, the magnet of the pole changer, key K, switch Q, contact button *2*, tongue b, stop c,

branch-office line, sounder S_2, key K_2, ground G_2, back to the starting point G. When the repeating transmitter, which by the way is a continuity preserving transmitter, opens, the tongue *b* comes in contact with the lever *a* and keeps the magnet of the pole changer closed through the following circuit: the battery B_1, magnet of the pole changer, the key K, switch Q, contact button 2, tongue *b*, and lever *a* of the repeating transmitter, back to the battery B_1. The number of cells in the batteries B and B_1 are so proportioned that the current through the magnet of the

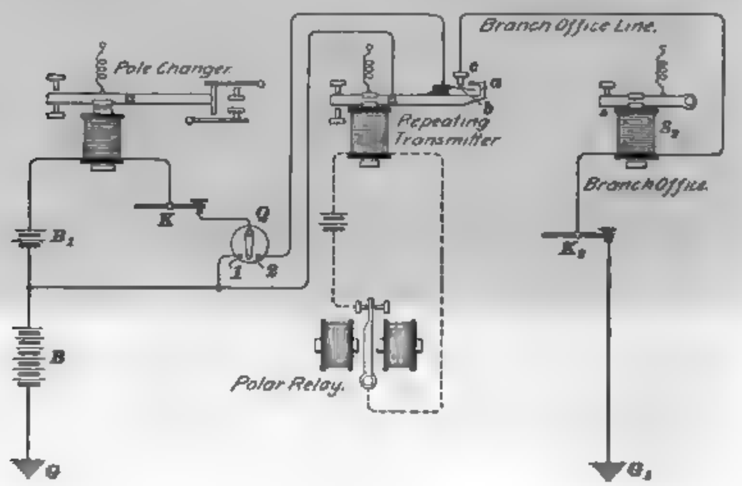


FIG. 5.

pole changer is the same in both positions of the repeating transmitter. Hence, the operation of the polar relay, which causes the repeating transmitter to send the message on to the branch office, does not operate the pole changer. When the branch-office operator wishes to send a message, the polar relay must remain closed in order to keep the repeating transmitter closed. In this position of the repeating transmitter, the tongue *b* rests against the stop *c* and the lever *a* is insulated from both *b* and *c*. The pole changer can now be controlled by the key K_2 or K. Thus it is evident that the branch-office operator may receive a message

rom one corner of the quadruplex set, or from the receiving side of a polar-duplex set, without the message being repeated back through the pole changer to the original sending station, and, furthermore, he may send a message to the distant quadruplex station through the pole changer.

MOFFAT'S DEFECTIVE-LOOP REPEATER.

14. Battery Arrangement.—The principle of Moffat's defective-loop repeater is well illustrated in Fig. 6. It is an application of the Toye-repeater principle; namely, the substitution of a resistance in place of the branch-office line circuit when the repeating transmitter opens. The arrangement shown in the figure illustrates the application of this principle to a polar duplex or to the polar side of the quadruplex system. It may also be applied to the neutral side of the quadruplex, in which case the pole changer and polar relay, shown in the figure, will be replaced, respectively, by the transmitter and repeating sounder on the common side of the quadruplex, the repeating transmitter magnet being connected to the back stop of the repeating sounder.

15. Operation.—The operation of this defective-loop repeater is as follows: When a message is coming over the quadruplex wire and through the polar relay, whose local circuit passes through the magnet of the repeating transmitter, the latter is operated. Thus, the circuit to the branch office is opened and closed at the stop *c* of the repeating transmitter, and hence the message may be read from the sounder *S*.

Although the repeating transmitter opens and closes the branch-office circuit, it does not open and close the circuit through the magnet of the pole changer; for in the closed position of the repeating transmitter, the circuit through the pole changer is closed through the tongue *b* and contact *c*, and the circuit may then be traced as follows: From ground *G*, through battery *B*, pole-changer magnet, tongue *b*,

contact c, branch-office line, sounder S, key K, ground G_2, and back to the original starting point G. The current in this circuit is sufficient to keep the pole changer closed. When the repeating transmitter is open, the pole changer

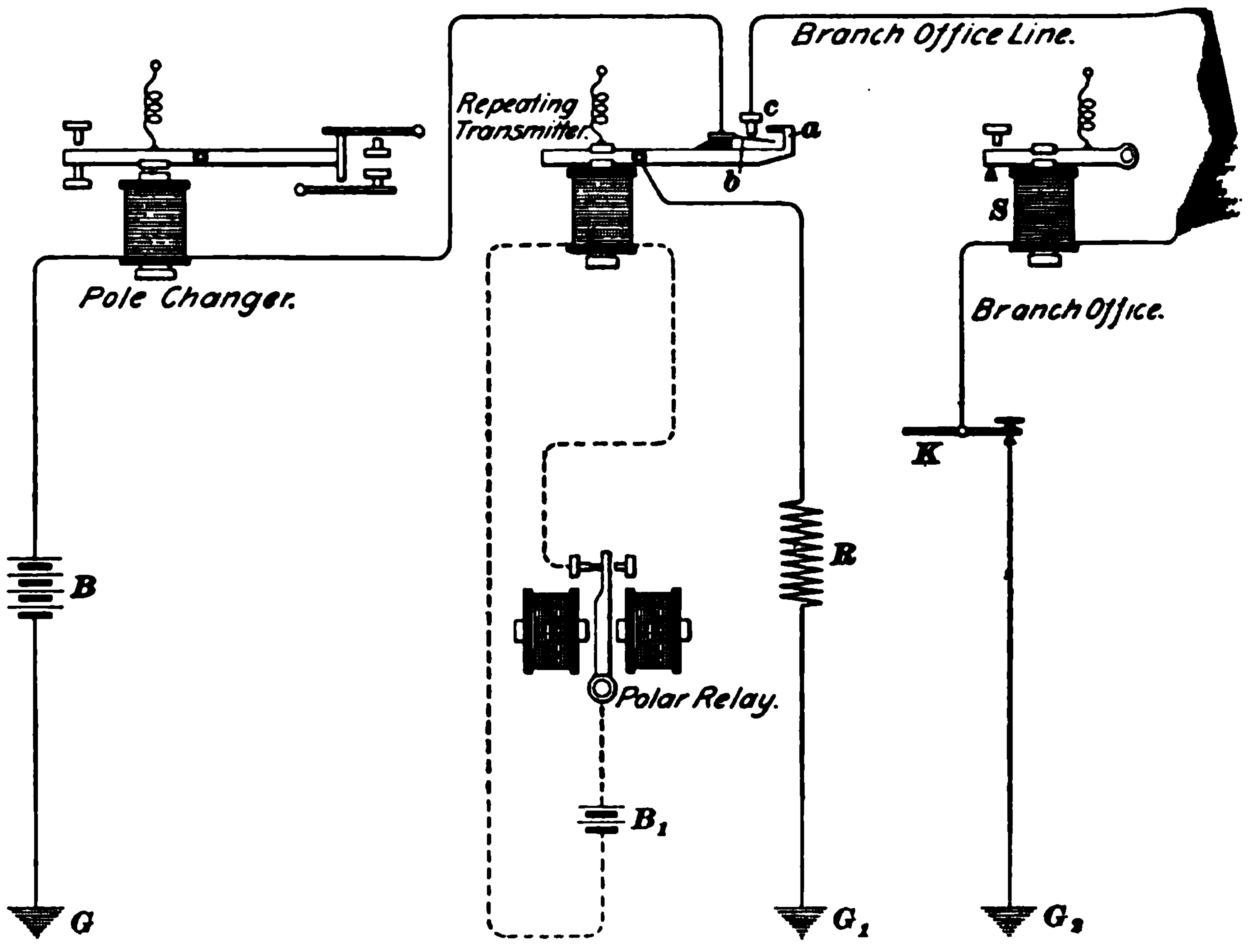


FIG. 6.

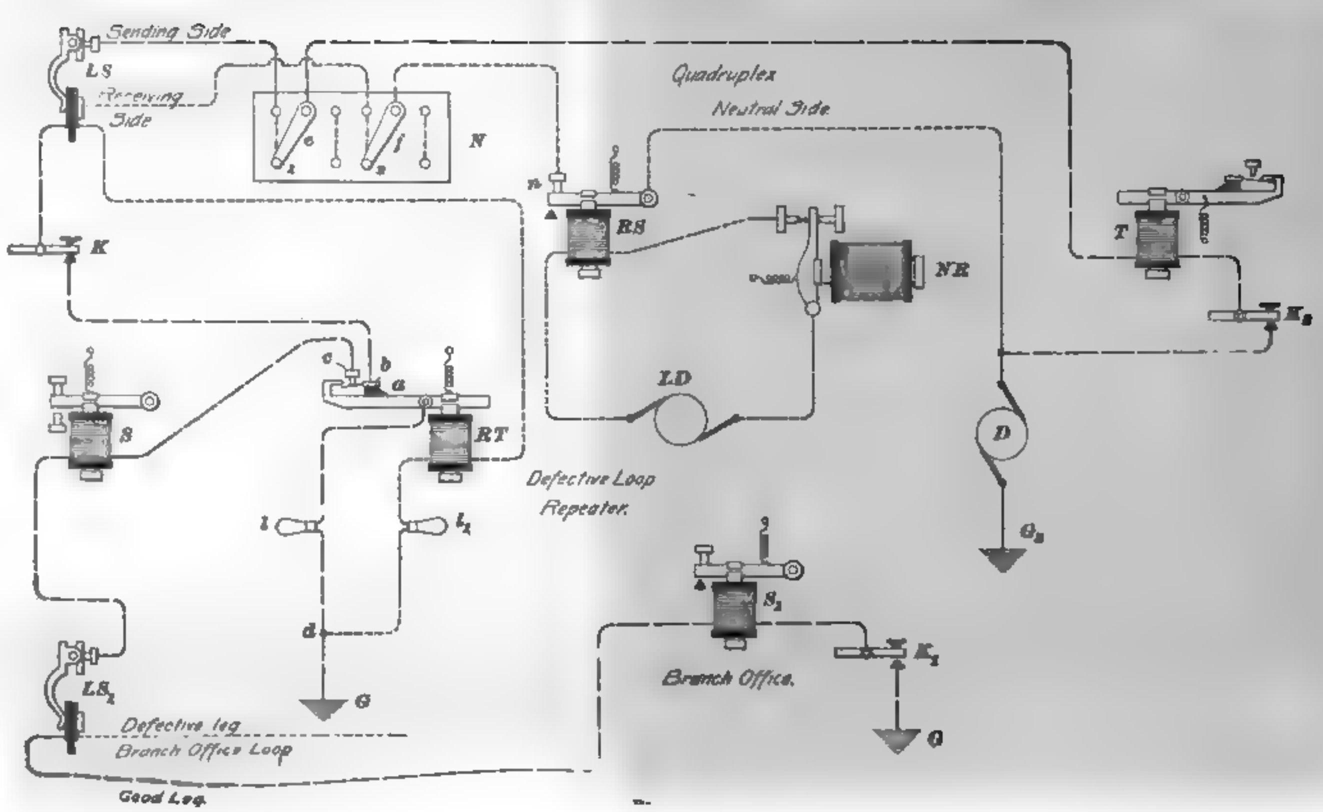
will still be kept closed by a current in the following circuit: From ground G, through battery B, magnet of the pole changer, tongue b, lever a, resistance R, ground G_1 and back to the starting point G.

16. The resistance R is made equal to that of the branch-office circuit, so that the same current will flow through the pole-changer magnet in both the open and closed position of the repeating transmitter. Furthermore, the repeating transmitter is a continuity-preserving device; consequently, the pole-changer circuit is not even opened when the repeating transmitter shifts from the open to the closed position, or *vice versa*. It is very necessary that the pole-changer circuit shall not be operated when a message is

being received through the polar relay. If this were not so and the operation of the polar relay should operate the pole changer, the message coming through the polar relay would be sent back by the operation of the pole changer to the same station from which it was sent.

17. To Send From Branch Office.—When the operator at the branch office is sending a message through the repeating office to the other end of the multiplex system, no message can be received over the polar relay, and it remains in its normal closed position, which causes the tongue *b* to remain in contact with the stop *c*. The operation of the key *K* will, in this position of the repeating transmitter, open and close the circuit containing the magnet of the pole changer; hence, the operator at the branch office can send a message through the near end of the multiplex system to the far end of the same system. Thus, the operator at the branch office can both send and receive through a duplex system or either side of a quadruplex system over one line wire.

18. Dynamo Arrangement.—The arrangement of Moffat's defective-loop repeater in Western Union offices, where dynamos are used, is shown in Fig. 7. The branch-office circuit is connected through a wedge to the loop switch LS_1, and the common side of the quadruplex is connected to the loop switch LS. The repeating apparatus consists merely of a repeating transmitter RT, two lamps l and l_1, the sounder S, and the key K. The latter two instruments enable the attendant operator at the repeating office to receive and send as well as to adjust and balance the system. The arms of the switch N rest upon the contact buttons *1* and *2* when the quadruplex apparatus is used in connection with the defective-loop repeater. It will be noticed that the repeating sounder RS, instead of being connected to the reading sounder on the common side of the quadruplex, is, in this case, connected directly with the switch N so that it controls the repeating transmitter. The repeating sounder is so connected that when it is in operation

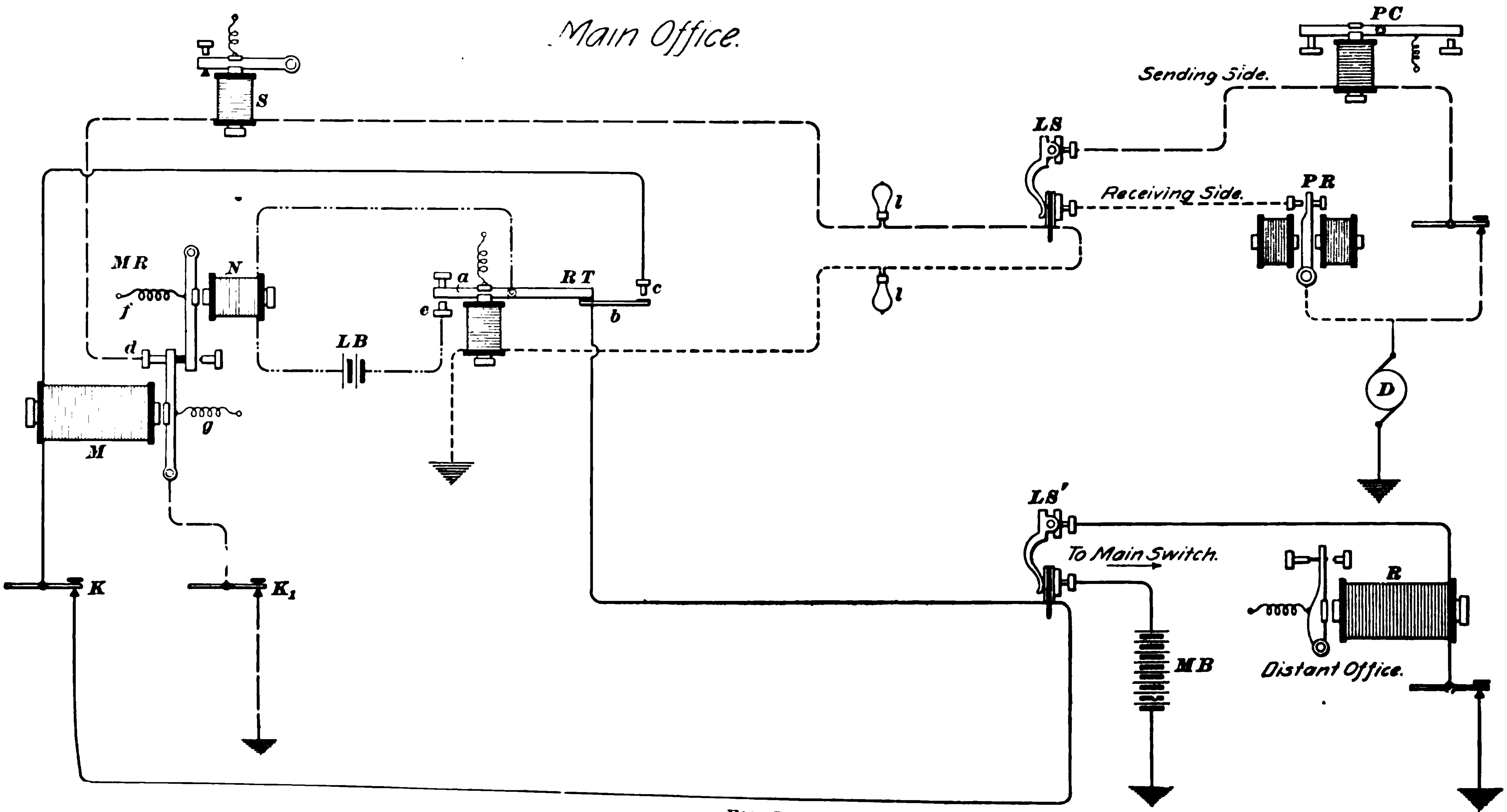


Sending Side
LS
Receiving
Side
N
Quadruplex
Neutral Side
RS
NR
T
K
K_2
LD
D
G_2
c
b
a
S
RT
Defective Loop
Repeater.
l
l_1
S_1
d
G
K_1
LS_1
Branch Office.
Defective leg
Branch Office Loop
Good Leg.

ɔpens and closes the good leg of the branch-office loop at ɜ stop c, but it does not open the sending side that passes ·ough the quadruplex transmitter T. This is very neces- ·y in order to prevent the operation of the transmitter T d the repeating of the message coming through the neu- ıl relay NR back to the original sending station.

19. When the local circuit of the repeating sounder is en at n, the repeating transmitter will open the good leg the branch-office circuit at c, and the sending side may traced from G_2 through the dynamo D, key K_2, trans- :tter T, switch arm e, contact button 1, loop switch LS, y K, the tongue b, lever a, lamp l, ground G, and back the starting point G_2.

When the repeating sounder RS is closed at n, as shown the figure, the repeating transmitter RT will close, using the tongue b to make contact with the stop c. The rcuit through the transmitter T is now closed through the ɔod leg of the branch-office circuit, instead of through e lamp l. The sending side may now be traced from G_2, 'namo D, key K_2, transmitter T, switch arm e, loop 'itch LS, key K, tongue b, stop c, the sounder S, loop ·itch LS_1, good leg of the branch-office loop, the branch- fice sounder S_1, and key K_1, to the ground G, and back to e starting point G_2. Thus the sending circuit through e magnet of the quadruplex transmitter T is kept closed .d the current is kept the same in strength in both posi- ɔns of the repeating transmitter RT. This is accom- ished by making the resistance of the lamp l equal to that the good leg of the branch-office loop, which it replaces ıen the repeating transmitter RT opens. Hence the anch office may receive a message coming through the :utral relay; furthermore, the branch-office operator may nd a message through the transmitter T, provided the peating transmitter RT is kept closed by the repeating under RS. This defective-loop repeater may also be ed on the polar side of the quadruplex or in connection th the polar duplex.



Main Office.
S
MR
N
f
d
M
g
K
K1
LB
a
e
RT
c
b
l
l
LS
Sending Side.
Receiving Side.
PC
PR
D
LS'
To Main Switch.
MB
R
Distant Office.

FIG. 8.

20. The lamp l_1 has such a resistance that the current furnished by the dynamo D will have the proper strength for working the repeating transmitter $R\ T$. When the magnet coils of T and $R\ T$ are equal in resistance, as they usually are, the lamps l and l_1 will each have the same resistance; consequently, these two lamps l and l_1 may be replaced by one lamp, if it is connected between the point d and the ground G.

As the branch-office line wire is used for both receiving and sending, it is evident that the branch-office key K'_1 must be in the half of the loop used. Hence, should the sending leg of the loop fail, the branch-office operator must reverse the sending and receiving sets, or else he must cut in his key in the receiving or good leg of the loop. The chief operator at the loop switch merely reverses the wedge of the branch-office loop in order that the good leg of the branch-office loop will face outwardly.

21. Where Used.—The Moffat detective-loop repeater is generally used where the resistances of all loops are approximately equal. When such is the case, the repeater is ready for instant operation the moment the two loops are inserted in the respective spring jacks at the loop switchboard, and it seldom requires attention or readjusting.

HALF-MILLIKEN REPEATER.

22. Where it is necessary to connect a polar duplex or one side of a quadruplex set with a main line, so that the distant end of this main line may both send and receive through one wire from the polar duplex, or the one side of the quadruplex, the **Half-Milliken repeater** may be used. This accomplishes for the long main line the same object as the defective-loop repeater does on short lines. The defective-loop repeater is not very suitable for use on long lines because the resistance of a long line is constantly changing more or less, whereas the Half-Milliken repeater

is perfectly satisfactory. Fig. 8 shows the Half-Milliken repeater connected through a loop switch *L S* with the duplex set, and through the loop switch *L S'* with the main battery, a main line, and a distant office. In a large office, the loop switch *L S'* would be connected by means of a flying loop to a main switchboard, to which the main line and the main battery are connected. The Half-Milliken repeater consists only of the Milliken double relay *M R* and a repeating transmitter *R T*. The sounder *S* and the keys *K* and K_1 are used for the convenience of the operator at the repeating station in reading the signals, adjusting the instruments, and communicating with the two distant offices. The Half-Milliken repeater is located at the main office containing the loop switches *L S* and *L S'*, the main battery *M B*, and the polar relay *P R* and the pole changer *P C*, which belong to a duplex or quadruplex set.

23. Operation.—In their normal condition all circuits are closed. Suppose that the polar relay is receiving a message over a duplexed wire. The opening of the polar relay *P R* will open the repeating transmitter *R T*. This will open the circuit containing the magnet *M* at *c* and the circuit containing the magnet *N* at *e*. But the spring *f*, being stronger than the spring *g*, will hold the circuit closed at *d*. Thus the sending side is not opened when the receiving side opens. However, the opening of the circuit at *c* opens the main-line circuit, and hence the distant-office relay *R* opens when the polar relay *P R* opens. Closing the polar relay will restore all circuits again to their normal closed position.

Suppose now that the distant office desires to send through the sending side of the duplex set. The distant office will open his key, thereby cutting off the current from the magnet *M*, and since the circuit through *N* has not been opened, the armature of the relay *M* will open the sending side of the duplex set at *d*. This will open the pole changer *P C* and, therefore, send a space from this main, or repeating, office over the duplexed wire to the polar relay at the distant main

office where the other end of the duplex set is located. When the distant office again closes his key, all circuits will again be restored to their normal closed position, thus sending a dot or dash to the distant main office. It has therefore been shown that the distant office is able to both send and receive by means of the Half-Milliken repeater through the duplex, or one-half of a quadruplex, set to the main office where the other end of the multiplex set is located. Moreover, this message may also be read on the sounder *S* at the main, or repeating, office.

REPEATER WITH RELAYS IN BRANCH-OFFICE LOOP.

24. Where it is necessary to connect a number of branch offices or a long line in circuit with a polar duplex or one side of quadruplex set, relays must be used in the place of the sounders for the same reason that relays are used on main lines. The branch-office circuit is then equivalent to a long main line, but the magnet of the pole changer or transmitter of the multiplex set cannot be connected directly in the branch line, but must be operated by a relay whose magnet is in the branch line.

Sometimes, six or eight offices are connected in one branch-office circuit in connection with a duplex or one side of a quadruplex set. Where this is the case, relays should be used and the apparatus connected as shown in Fig. 9. The Toye-repeater principle is used here. Practically the only difference between this and the defective-loop repeater shown in Fig. 7 is a substitution of relays for sounders at the branch offices and the use of a relay *R'* at the repeating office for controlling the quadruplex transmitter. When a return circuit, as shown here, is used, instead of grounding the circuit after passing through the last branch office, a resistance box *Rh* may be used. This box allows the resistance of the branch-office loop to be increased so that ordinary relays suitable for use with the main-line battery *M B* or a dynamo may be used.

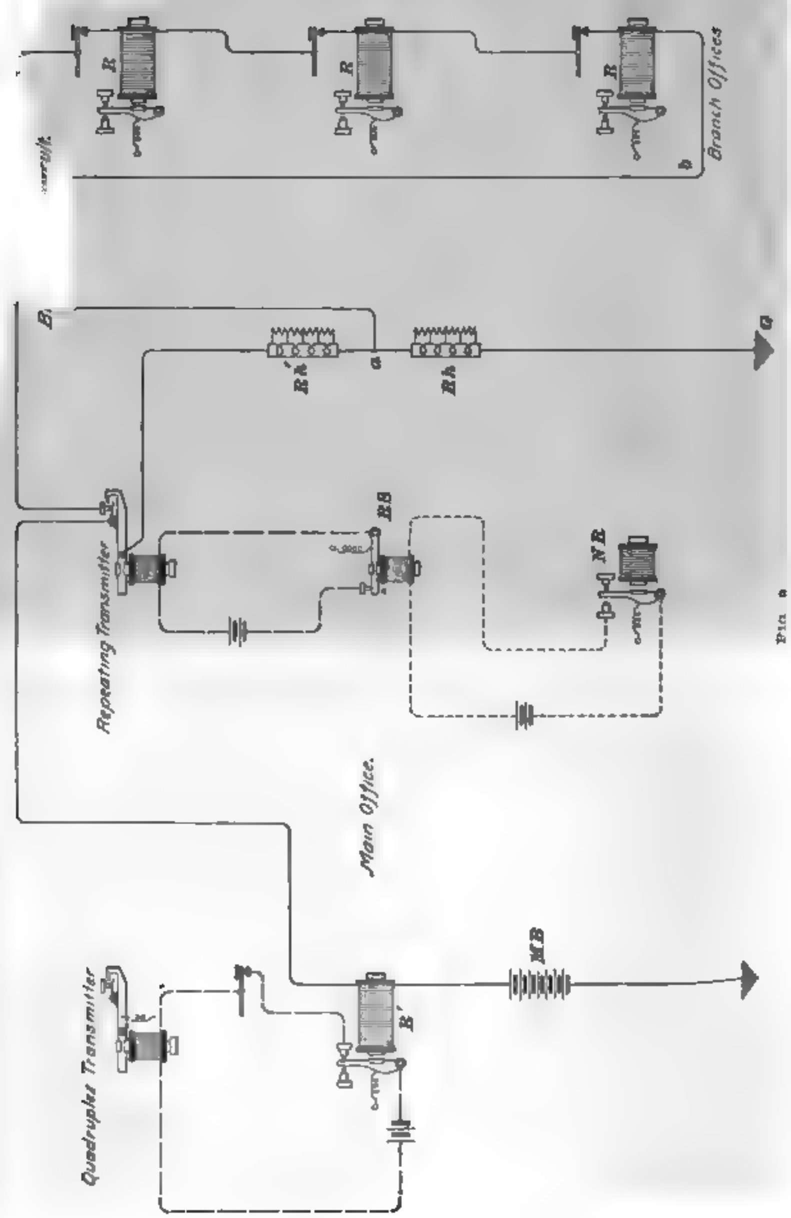

Quadruplex Transmitter
Repeating Transmitter
Main Office.
Branch Offices
B'
MB
BS
NR
Rh'
Rh
a
b
R
R
R
G

Fig. 9

Evidently the resistance of Rh' should be equal to the total resistance of the branch-office circuit back to the point a. In case the branch-office circuit is grounded and there is no return wire $b\ a$, then only one resistance box Rh' will be necessary, and its resistance should be made equal to the resistance of the one branch-office wire and all the branch-office relays to the ground at the most distant branch office. The resistance Rh', as in the Toye repeater, causes the relay R' and, consequently, the quadruplex transmitter to remain closed when the repeating transmitter is open.

BRANCH-OFFICE SINGLE OR DUPLEX ARRANGEMENT.

25. Fig. 10 shows an arrangement whereby the apparatus at a branch office may be used in a single or duplex circuit. When the switches E and F are turned to the left,

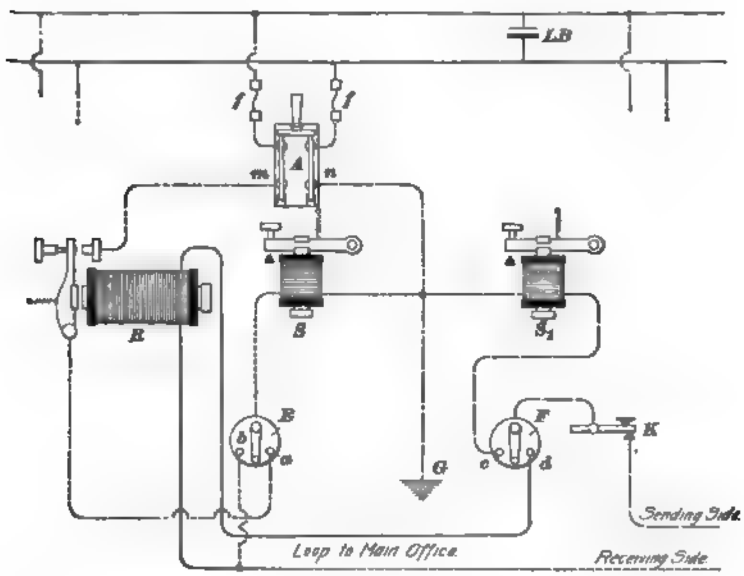


FIG. 10.

the apparatus is arranged to work on the sending and receiving sides of the duplex set at the main office. In this case

ing side may be traced through the key K, switch F, button c, sounder S_1 to the ground G; and the receiving side through the contact button b, switch E, and the sounder S_1 to the ground G.

To use the key K, relay R, and the sounder S as a single Morse set, the switches E and F are both turned to the right. Then the circuit may be traced from the sending side of the loop through the key K, switch F, contact button d, relay R, to the receiving side of the loop. With the switches in this position, the sounder S_1 is on open circuit. Thus in the circuit from the main office there is now only the key K and the relay R, which controls the sounder S.

The local circuit containing this sounder is supplied with current from the local battery L B, which is arranged here as it would be if it were a storage battery that supplied several local circuits. If a gravity battery were used, it would be connected between the points m and n and no switch A would be necessary. It would supply only this one local circuit.

DILLON BRANCH-OFFICE QUADRUPLEX REPEATER.

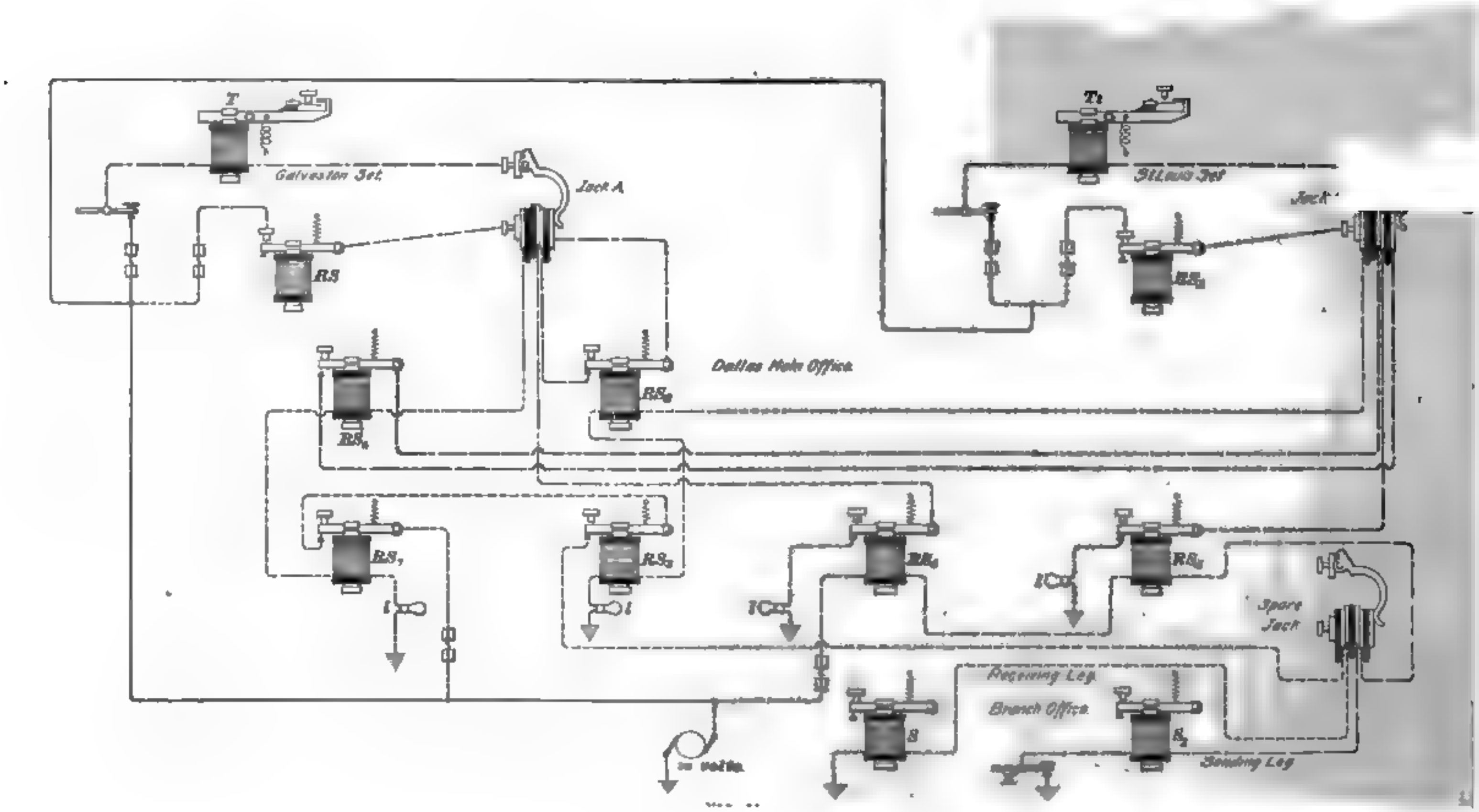
26. Mr. James B. Dillon gave in the "Telegraph Age," March 16, 1900, an arrangement suitable for use in Western Union offices by which a branch-office loop may be connected in circuit with the multiplex apparatus at a repeating station, in such a manner that the terminal offices on the multiplex sets may work single, but without interference from the branch office, although the latter is able to hear and break either terminal of the multiplex that may be sending. Thus the branch office can take a drop copy without requiring help in order to break one of the distant senders, and the branch office can send to both terminal offices.

Such an arrangement is often of considerable use to chief operators in large offices where newspapers desire to send the same copy to two stations by repeating through the

office where the newspaper branch-office loop terminates. The difficulty with most of the present temporary makeshifts is that, while the newspaper office can send to both terminals at once, the latter cannot hear each other, which frequently leads to confusion.

The arrangement and connection of the apparatus for accomplishing the object desired is shown in Fig. 11. The transmitter T and the repeating sounder $R S$ constitute the common side at the Dallas main office of a quadruplex system extending from Dallas to Galveston. Of course the apparatus on the polar side can be substituted in place of that shown here on the common side. T_1 and $R S_1$ constitute the apparatus on the common side at the Dallas main office of the quadruplex system between Dallas and St. Louis. The local connections only are shown here. The quadruplex apparatus is shown connected to the jacks A and B, as in most Western Union offices. The two wires from the contact stop and lever of $R S_6$ would, in practice, be run to opposite sides of the front wedge in jack B, and the wire from the lever of $R S_6$ would run to the front side of the middle half-wedge, instead of being connected as shown here. However, the repeater will work all right either way.

27. Operation.—Normally, all circuits are closed. Opening the key in the transmitter circuit at the distant Galveston office will open the local circuits controlled by the repeating sounders $R S$, $R S_6$, and $R S_7$. This will cause the message to be heard at the Dallas main office on $R S_6$ and $R S_7$. Furthermore, the operation of the repeating sounder $R S_6$ will cause the message to be repeated through the quadruplex transmitter T_1 of the St. Louis set at Dallas to St. Louis, and the operation of the repeating sounder $R S_7$ will cause the message to be heard on the sounder S in the receiving leg at the branch office. Operating the transmitter key at the distant St. Louis office will operate the repeating sounders $R S_1$, $R S_2$, and $R S_3$. Thus the message will be heard in the main office at Dallas on $R S_2$ and $R S_3$.

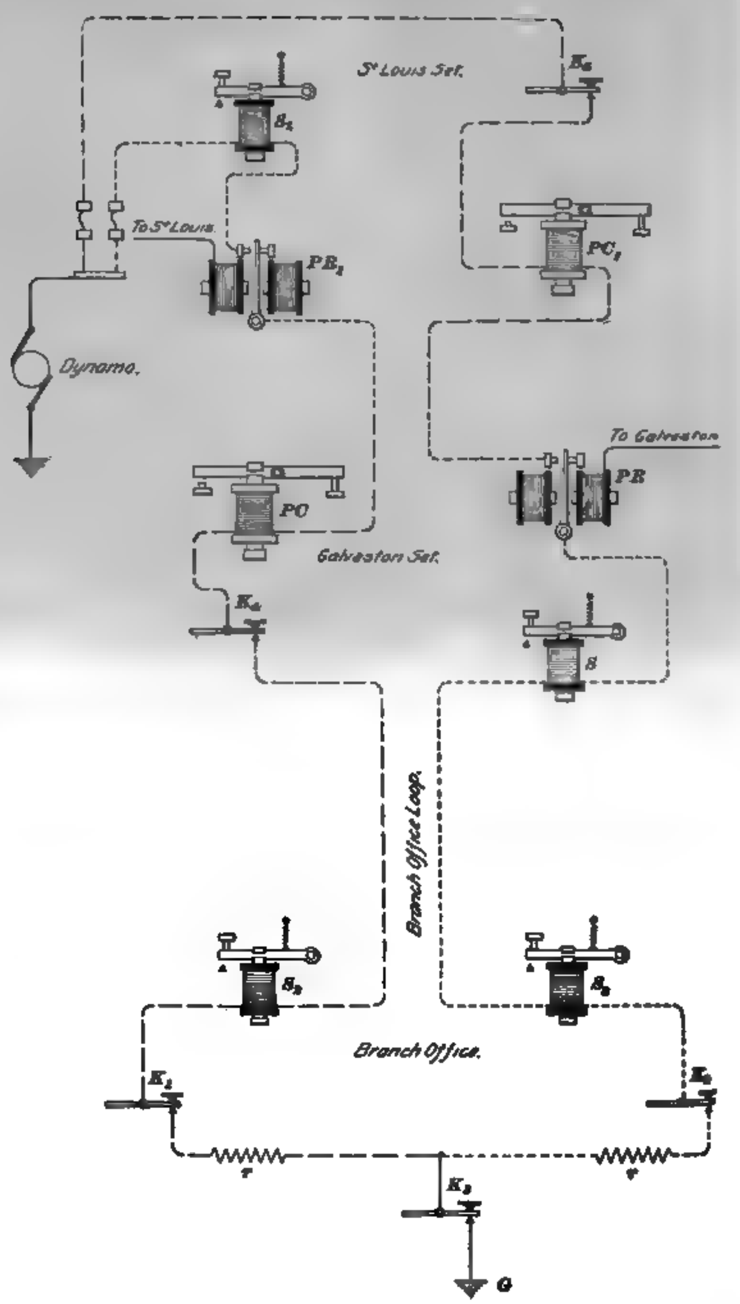


Galveston Set
Jack A
St Louis Set
Dallas Main Office
Spare Jack
Receiving Leg
Branch Office
Sending Leg

Furthermore, the operation of the repeating sounder RS_2 will evidently operate the transmitter T in the Galveston set at Dallas, causing the message to be sent to Galveston, and the operation of the repeating sounder RS_3, provided RS_7 remains closed, will cause the message to be sent through the receiving leg of the branch-office loop to the branch-office sounder S.

28. Double-Sending Possible Between Terminal Stations.—Operators at Galveston and St. Louis can send simultaneously, provided the key K at the branch office in the sending leg is closed, and the messages will be repeated properly at Dallas. Thus the two ends can work double, provided the branch-office key is kept closed. However, the branch office cannot, in this case, read either message because the two messages will interfere with each other in the receiving leg of the branch-office loop, due to the simultaneous operation of the two sounders RS_7 and RS_3. If the branch office sends by operating the key K, then the repeating sounders RS_4 and RS_5 are operated. The operation of RS_4, provided RS_2 remains closed, causes the message to be repeated through the transmitter T of the Galveston set at Dallas to Galveston. Similarly, the operation of the repeating sounder RS_5, provided RS_6 remains closed, causes the message to be repeated through the transmitter T_1 of the St. Louis set at Dallas to St. Louis. Hence the branch office can send to both ends of the main circuit by operating the key K in the sending leg at the branch office. When the branch office is sending, the local circuits of both repeating sounders RS and RS_1 must remain closed in order to keep RS_6 and RS_2 closed; hence, no message can be received either from Galveston or St. Louis while the branch office is sending and, therefore, in this case the line can only be worked single.

29. Thus any one of the three offices, St. Louis, Galveston, or the branch office in Dallas, can send to the other two by working the line single; and the two terminal offices,



St Louis Set.
K_6
S_1
PC_1
To St Louis.
PR_1
Dynamo.
To Galveston
PR
PC
Galveston Set.
K_4
S
Branch Office Loop.
S_2
S_3
Branch Office.
K_1
K_2
r
r
K_3
G

FIG. 19.

St. Louis and Galveston, can work the line double if the message is not intended to be received at the branch office in Dallas and provided the branch-office key in the sending leg is kept closed.

POSTAL TELEGRAPH BRANCH-OFFICE QUADRUPLEX REPEATER.

30. The same result obtained by the arrangement of the apparatus given in Fig. 11 may be accomplished in a much simpler manner by an arrangement shown in Fig. 12 that may be used in Postal Telegraph offices. For the sake of simplicity, all switches have been omitted in this figure. The apparatus in the upper part of the figure is located at the Dallas repeating office and represents the polar duplex, or the polar side of a quadruplex set, the other end of which is in St. Louis. The apparatus in the middle of the figure represents a polar duplex, or the polar side of a quadruplex set, the other end of which is in Galveston. As in the preceding figure, only the local connections are here shown. The only extra piece of apparatus used is the key K_3 at the branch office. It is connected, as shown, between the junction of two resistance coils r, r and the ground G. The resistance coils r, r are adjusted to give all local instruments their required current. These two resistances can be located at the main office instead of at the branch office.

31. Operation.—The operation of the key K_3 sends the message to the repeating office at Dallas, to St. Louis, and to Galveston. For, opening the key K_3 opens the circuit through the magnets of both the St. Louis and the Galveston pole changers $P\,C_1$ and $P\,C$, respectively, at the Dallas repeating office; hence the message is repeated through these pole changers to St. Louis and Galveston. Operating the key K_1 at the branch office sends the message to the Dallas repeating office, where it operates the pole changer PC and so repeats the message to Galveston. Operating the key K_2, similarly, sends the message to the Dallas repeating office and to St. Louis. Evidently, a message

may be sent from the Dallas repeating office to the branch office and to Galveston by operating the key K_1; similarly, a message may be sent from the Dallas repeating office to the branch office and to St. Louis by operating the key K_2.

32. The operation of the pole-changer key at St. Louis will send the message to the Dallas repeating office and to the branch office, the message being received on the sounders S_1 and S_2, respectively; and by the repeating action of the pole changer $P C$, the message will also be sent to Galveston. Similarly, Galveston can send to the Dallas repeating office, the branch office, and to St. Louis; furthermore, St. Louis and Galveston can be sending simultaneously and each message will be received at the Dallas repeating office, at the branch office, and at one of the two terminal stations. When the branch office sends by means of the key K_3, the line between Galveston and St. Louis can only be worked single.

The arrangement given here enables an operator at the branch office to send to the repeating office and to either terminal station by the key K_1 or K_2, or to the repeating office and to both terminal stations by key K_3. Furthermore, he can hear the message sent from both ends when they are working double. Consequently, there should be no confusion at any time due to the operator at either end or in the branch office not hearing the others sending.

DOUBLE-LOOP REPEATER.

33. It is sometimes desirable to connect two branch offices with a duplex set or one side of a quadruplex set at the main office in such a manner that both branch offices may receive the message coming over the receiving side of the multiplex set, and also allow either branch office to send to the other branch office and through the sending side of the multiplex set at the nearer main office to the distant main office. An arrangement of apparatus that will accomplish this is called a **double-loop repeater.**

Fig. 13 illustrates a double-loop repeater that is frequently used. It consists of three transmitters, a repeating sounder, and one ordinary sounder. As in all repeaters, it

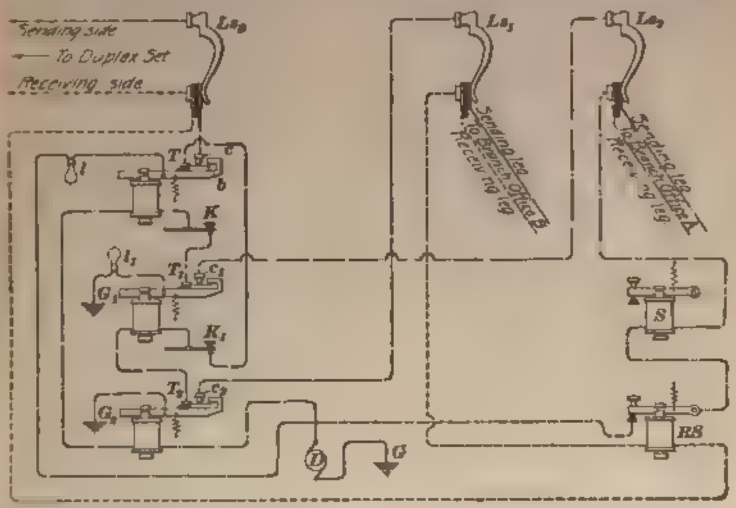


FIG. 13.

is very necessary that the opening of the key in the sending circuit at either branch office or at the repeating station shall not leave the sending circuit open at the repeating station.

34. Operation.—In explaining the operation of the double-loop repeater, we will first assume that all circuits are in their normal condition, that is, closed. Suppose now that the polar relay in the duplex set connected to the loop switch Ls_2 in the figure opens the receiving side. This will cut off the current from the magnet of the repeating sounder $R S$ and also from the sounder in the receiving leg at the branch office B. Furthermore, the opening of the repeating sounder $R S$ will cut off the current from the sounder S and also from the sounder in the receiving leg at the branch office A. Hence, the opening of the circuit at the polar relay has cut off all current from the receiving legs of the two branch-office loops and from the sounder S.

The sounder S is used to enable the attendant to read the signals in order to judge whether the circuit is working properly and to communicate with the branch office.

35. Suppose that the branch office A desires to send to the branch office B and through the sending side of the duplex set to the distant main office. When the key in the sending leg at the branch office A is opened, there will be no current through the magnets of the transmitters T and T_2, thus allowing these two transmitters to open. The opening of the transmitter T will open the sending side of the duplex set at contact stop c and, hence, operate the sending side of the duplex set. When the transmitter T opens, however, the tongue of the transmitter is connected through the lever, lamp l, and dynamo D, to the ground G. Since the lamp l has a resistance equal to that of the sending side of the duplex set that was cut out at c, the current flowing through the magnet of the transmitter T_1 will remain constant and thus the transmitter T_1 will be kept closed. This is essential in order that the sending circuit from the branch office A shall not be opened at the repeating station. The opening of the transmitter T_2, by disconnecting the tongue from the contact stop c_2, has opened the sending leg running to the branch office B; and by connecting the tongue to the ground G_2, the opening of the transmitter T_1 has been prevented by the substitution of a circuit to the ground G_2 for the sending leg from c_2 through the branch office B. Thus the opening of the key in the sending leg at the branch office A has opened the sending leg to the branch office B and the sending side of the duplex set, but has not opened the sending leg of the branch office A at the repeater. No lamp is required between the lever of the transmitter T_2 and the ground G_2, because the lamp l is in the circuit between G_2 and the dynamo whenever the transmitters T and T_2 are open.

36. Suppose that the circuits are again in their normal closed condition and that the key in the sending leg at the branch office B is opened. This will open the circuit through

the transmitter T_1 and also through the sending side of the duplex set. When the transmitter T_1 opens, it opens the sending leg to the branch office A at contact c_1, but the tongue of this transmitter T_1 comes into contact with the lever and makes a connection through the lamp l_1 with the ground G_1, thus keeping the transmitters T and T_2 closed. Thus the opening of the key in the sending leg at the branch office B has opened the sending leg running to the branch office A and also the sending side of the duplex set. Furthermore, the operation of the transmitters has been such that the sending leg from the branch office B has not been opened at the repeating station. Thus it has been shown that both branch offices may receive a message from the receiving side of the duplex set and that either branch office may send to the other branch office and through the sending side of the duplex set to the distant main office.

THREE MULTIPLEX SETS CONNECTED TOGETHER.

37. A method of arranging three quadruplex sets in such a manner that they will be in communication with one another when worked as a single line, or where any two can be worked double, provided the third station keeps his key closed, is shown in Fig. 14. This arrangement was given by Mr. J. B. Dillon, in the "Telegraph Age," April 1, 1900. The repeating sounders shown in this figure can be replaced by transmitters properly connected or by pony relays of the proper resistance. The resistance of the various circuits should be adjusted by the use of lamps or resistance coils to allow the various instruments the proper amount of current.

38. Operation.—If when all keys are closed and quadruplex A wishes to work with B and C, the operation is as follows: Opening the key at the distant office A causes polar relay A and the repeating sounders $R\,S$ and $R\,S_1$ to

open, thereby opening the circuits passing through the pole changers of the quadruplex sets B and C, respectively, thus sending the signal to the distant quadruplex stations B and C

Should the distant office B desire to break, the opening of his key will cause the polar relay B and the repeating sounders RS_2 and RS_5 to open, thereby opening the circuits passing through the pole changers of the sets A and C—it, of course, being understood that the operator at the pole-changer key at the distant office A will close his key when he hears the opening of his sounder controlled by his polar relay, and thus permit the office C, as well as the office A, to hear what the operator at the pole-changer key at the distant office B has to say.

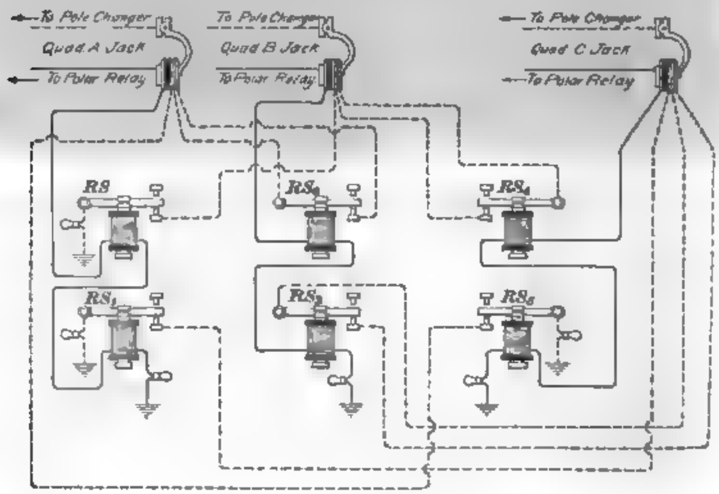


FIG. 14.

Should the distant operator C desire to send, the opening of his key will open the polar relay at the set C and cause the repeating sounders RS_4 and RS_5 to open the circuit passing through the pole changers of the quadruplex sets B and A, respectively. It will thus be seen that each

station can hear and converse with any other as a single-circuit arrangement.

39. Two Offices Working Double.—To show how any two offices can work double, provided the third station keeps his key closed, suppose that *A* and *B* desire to work double, while the key at the distant office *C* is kept closed. The path of the current through the pole changer of the *A* set may be traced through the front wedge in the quadruplex *A* jack, the cord, and contact points of the repeating sounder $R\,S_2$, thence back to the other side of the same wedge, through the center half-wedge, the cord, and the contact points of the repeating sounder $R\,S_6$ to the ground. As the repeating sounder $R\,S_2$ is controlled by the polar relay of the *B* set, it will be readily seen that the distant *A* operator will then hear what the distant *B* operator has to say. The path of the current through the pole changer of the *B* set may be traced through the front wedge in the quadruplex *B* jack, the cord, contact points of the repeating sounder $R\,S_4$, the cord, the other side of the same wedge, the center half-wedge, thence through the contact points of the repeating sounder $R\,S$ to the ground. As the repeating sounder $R\,S$, which controls the pole changer of the *B* set, is in turn controlled by the polar relay of the *A* set, it is evident that the distant *B* operator will hear what the distant *A* operator has to say.

40. If *A* and *C* wish to work double, *B* must keep his key closed. The repeating sounder $R\,S_1$ will then operate the pole changer of the set *C*, and the repeating sounder $R\,S_6$ will operate the pole changer of the set *A*. Confused signals, due to the sending at both *A* and *C*, which operate the repeating sounder $R\,S$ and $R\,S_4$ (as well as $R\,S_1$ and $R\,S_5$), will pass through the pole changer of the set *B*; hence neither message can be read at the distant office *B*. Should *B* and *C* desire to work double, *A* must keep his key closed.

41. While the third quadruplex will be practically dead, as far as business is concerned, when the other two are

working double, attention is merely called to the fact that doubling is practicable, as explained, should it be desirable to connect three quadruplex sets for special or report matter (worked as a single line).

CARE OF MULTIPLEX SINGLE-WIRE REPEATERS.

42. The repeating transmitters of multiplex single-wire repeaters must be kept in good order, the contacts must be kept clean, and the tongue of the transmitter must not be too stiff. If the contacts of the repeating transmitter become dirty, a message coming over the polar relay or the neutral relay will be repeated back through the pole changer or transmitter to the original sending station. For it is evident that a dirty contact may prevent the repeating transmitter from holding the pole changer or transmitter of the multiplex set closed when a message is coming through the polar or neutral relay. In case a single-wire repeater is used at both ends of the multiplex system, utter confusion might result from defective contacts on both repeating transmitters.

The second source of trouble may be due to the fact that the current through the pole changer or transmitter of the multiplex set is not the same in the two positions of the repeating transmitter. This may be due to a weakening of one of the batteries, or to the fact that the resistance used in repeaters (depending on the principle used in the Toye repeater) to take the place of the branch circuit in the open position of the transmitter is not properly adjusted. If the two currents are unequal for either of the reasons given above, and if the spring of the pole changer or transmitter of the multiplex set is adjusted properly for the stronger current, the instrument may open when the weaker current passes through it instead of remaining closed as it should. This, of course, may be avoided by making the strength of the current through the pole changer or transmitter of the multiplex set the same in both positions of the repeating transmitter.

If the tongue of the quadruplex transmitter is too stiff, it will not break contact properly with the lever, as it should do, when the repeating transmitter is opened; especially will this be the case should the local battery in the quadruplex transmitter be weak at the same time. The faults that have been enumerated do not include, of course, faults due to the improper adjustment and balance of the duplex or quadruplex system itself. The latter have already been given in connection with the adjustment and balancing of the quadruplex system.

BRANCH-OFFICE SIGNALING DEVICES.

43. Where wires are rented to brokers or others, it is necessary in order to report any trouble that may occur in their circuits that they shall be able at all times to signal the main office, which is responsible for the condition of the line.

As vibrating bells or buzzers are generally used in connection with these branch-office signaling devices, it will be well to describe them first. The only difference between a vibrating bell and a buzzer is that, in the case of the bell, the vibrating armature of the electromagnet is allowed to tap a gong, whereas in the buzzer it merely vibrates between two stops. The construction and operation of the annunciators that are used in this connection will be clear from the diagrams in which they are shown.

VIBRATING BELL.

44. Construction.—The bell used for battery call work is usually of the type known as the **vibrating** or **trembler bell,** one form of which is shown in Fig. 15. The hammer of this bell is arranged so as to vibrate rapidly back and forth and to strike the gong at each vibration, producing a continuous succession of sounds. D and D' are two electromagnets having cores F and F' of soft iron secured to a soft iron yoke piece Y. G is a soft iron armature

mounted by means of a flat spring S secured to a post P, so as to vibrate freely in front of the cores l and l'. The armature carries a hammer, as shown, adapted to strike the gong a sharp blow when the armature is pulled toward the magnet cores. If the circuit through the magnets passed from one binding post t through the coils directly to the other binding post t', then closing the circuit containing a suitable battery would cause the hammer to strike the gong a single blow.

A succession of blows might be produced by rapidly making and breaking the circuit at the point from which the signal was being sent; but this would be an unsatisfactory method. Therefore, the armature of the bell is so arranged as to make and break the circuit by its own vibration. In this way a rapid and continuous succession of strokes is produced as long as the terminals of the battery are connected to the two binding posts t and t'. To bring about this result, the circuit between the binding posts of the bell is made as follows: From the binding post t, which is insulated from the frame of the bell, a wire leads to one terminal of the coils D and D', which are connected together in series. A wire leads from the other terminal of D to the metallic post N, which is insulated from the metal framework and provided with a contact screw M. When the armature is at rest, a contact spring N, carried by the armature, rests against the contact screw M, thus carrying the circuit to the armature and the post P. This post P is connected with the frame of the bell, as is also the post t', so that the circuit from P to t' is completed through the metal frame itself. When a current is sent through the coils,

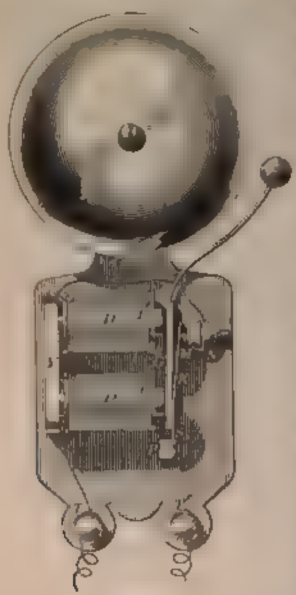


FIG. 15.

the armature will be drawn forwards, thus causing the hammer to strike the gong. This movement, however, will break the circuit by causing the spring X to move out of contact with the screw M. This interrupts the flow of current through the coils, and therefore allows the armature to spring back, it being no longer attracted by the magnet cores. In doing this, contact is again made between the spring X and the screw M, thereby completing the circuit and again energizing the magnets, thus producing another stroke of the hammer. This process is repeated as long as the battery circuit remains closed. The spring X is provided so that the circuit will not be broken quite as soon as the armature starts to move toward the cores. Its function is to prolong the time during which the circuit is closed, so as to allow the magnets to exert a pull on the armature until the hammer is almost in contact with the bell.

45. Design.—These bells are manufactured in almost numberless styles, many of which are of exceedingly poor design, from both mechanical and electrical standpoints. A good battery bell should be so well constructed that none of its parts are likely to work loose because of the rapid and violent vibration of the hammer. The point of the screw M and also the surface on the spring X should be tipped with platinum, in order that the surface of the contacts may be kept clean, as platinum will not corrode under ordinary atmospheric conditions, and is, moreover, not much affected by the electric spark, which is sometimes very heavy between these contacts. Silver, being cheaper, is frequently used in place of platinum, and is superior to copper, brass, and iron. The screw M should be provided with a locknut, or with some other means of locking it securely in any position to which it has been adjusted. If this is not done, the vibration of the armature will cause the screw to gradually work back until finally it reaches a point where the spring X will not make contact with it. This locking is sometimes accomplished by splitting the post N, so that the screw threads in the two halves exert a

combined action on the screw, due to the elasticity of the parts of the post.

46. Prevention of Sticking.—Means must be provided for preventing the armature from coming into actual contact with the poles of the electromagnet, as the residual magnetism will cause it to stick and not allow the spring *S* to move it back at once or at all. This may be done in a number of ways, one of which is to secure a thin strip of copper to the surface of the armature which would otherwise come in contact with the poles. Another way is to insert a small pin of brass or copper into the ends of the poles in such a manner that it will project slightly beyond the pole surfaces. Either of these methods should prevent actual contact between the iron surfaces and therefore eliminate this tendency to stick; which is particularly great where the magnets and armature are not of the best quality of soft annealed iron, because hard iron retains its residual magnetism with more tenacity. In a first-class bell these parts are made of the softest grade of wrought iron, so as to be readily demagnetized when jarred by the striking of the armature against the cores.

47. Adjustment.—The adjustment of battery bells is a very simple matter, for usually the turning of the screw *M* until it occupies the desired position is all that is required. The best position may be determined by gradually turning this screw, while the circuit is closed, until the hammer vibrates in such a manner as to produce a succession of hard, sharp blows against the gong. If the screw *M* is too far back, the circuit will be opened before the armature has acquired sufficient momentum to carry the hammer to the gong; or it may be so far back as not to allow the circuit to be completed at all. On the other hand, if the screw is too far forwards, the spring *X* will not be pulled away, and the circuit will not be broken; or else the break will occupy such a short space of time that the hammer will not be allowed to recede far enough to strike a proper blow upon the gong. If the adjustment by means of the

screw *M* does not produce the desired results, it may be that the armature *G* does not occupy a proper position with respect to the poles of the magnet. When the hammer rests against the gong, the distance between the armature and each of the pole pieces should be approximately the same. This adjustment, as a rule, may be made by bending the spring *S* slightly or by shifting the position of the magnets.

48. Sometimes the surface of the gong against which the hammer strikes does not occupy such a position as to allow the hammer to strike it at the proper moment. If the gong in Fig. 15 is too far to the right, the hammer will strike before the armature has moved far enough toward the pole pieces to allow them to attain the maximum pull. If the gong is too far to the left, then the armature will strike the pole pieces before the hammer strikes the gong; in either case a loss of efficiency will result. This may be remedied by bending the rod on which the hammer is mounted, but in many cases a better way is to turn or move the gong itself on its standard. These gongs are usually somewhat eccentric, due to imperfections in their manufacture, and therefore by turning them the surface against which the hammer strikes may be brought into the correct position.

49. Fig. 16 shows such a bell connected in circuit with a battery and push button. By pushing the button, the

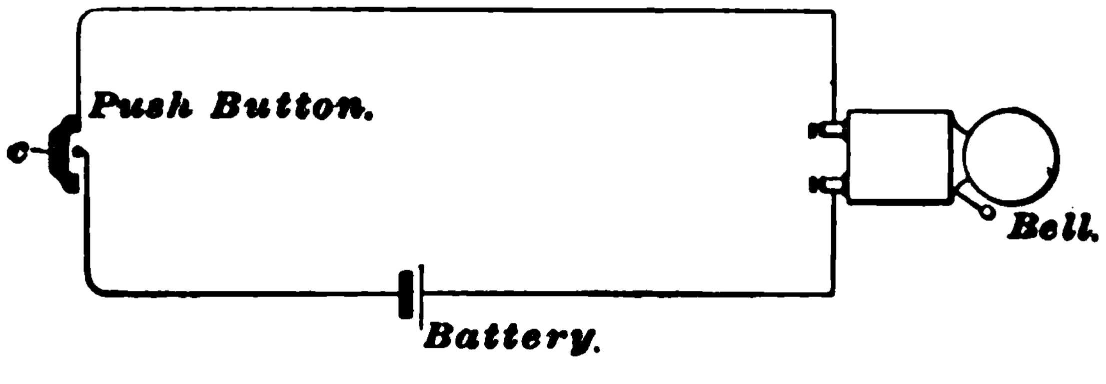


FIG. 16.

circuit is closed at *c*, thus allowing the action already described to take place. This circuit is such as would be used for an ordinary push-button call for almost any purpose.

HURD BRANCH-OFFICE SIGNALING DEVICE.

50. Loops that are extended to branch offices are usually connected through an annunciator at the main office. These annunciators are all grouped at one board, where they are looked after by an attendant. The method devised by Mr. J. B. Hurd is shown in Fig. 17. At the branch office there is a three-point switch *Q* that ordinarily remains in a central position, thus insulating the ground *G*. Ordinarily the current through the branch-office loop apparatus has not sufficient strength to attract the armature *d* of the main-office annunciator *A*. Thus the annunciator shutter *e* is ordinarily held up by the hook on the front end of

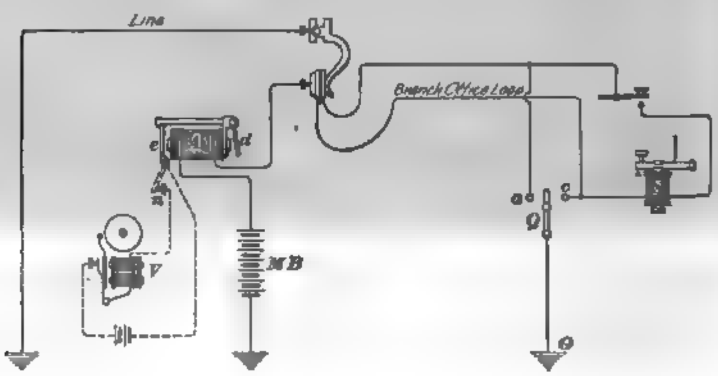


FIG. 17.

an arm that is rigidly fastened to the armature *d*. However, the branch-office operator, should he desire to attract the attention of the attendant at the main-office annunciator board, turns the arm of the switch *Q* to the contact button *c* so as to ground the low-resistance side of the circuit. This cuts out one wire of the branch-office loop and the branch-office instruments and thus allows enough current to flow from the main battery *M B*, through the coil of the annunciator *A*, one wire of the loop circuit, and the ground to drop the shutter *e* to the dotted position against the contact stop *n*.

51. It is usual to arrange the shutter of the annunciator in this manner, so that when it falls, a local circuit containing a buzzer or bell and a battery will be closed, thus attracting the attention of the attendant.

The switch *Q* is provided with two contact buttons *a* and *c* so that the ground can be connected to either side of the circuit. Thus, in case the two sides of the branch-office loop are reversed at the main office, the branch-office operator can still operate the annunciator. Behind the shutter *e* is the name of the branch office that is connected to this annunciator. The magnet of the annunciator is usually of low resistance, about 2 or 3 ohms.

DUPLEX CALL.

52. An arrangement for calling on a duplex circuit is shown in Fig. 18. An extra neutral relay *N R* and vibrating

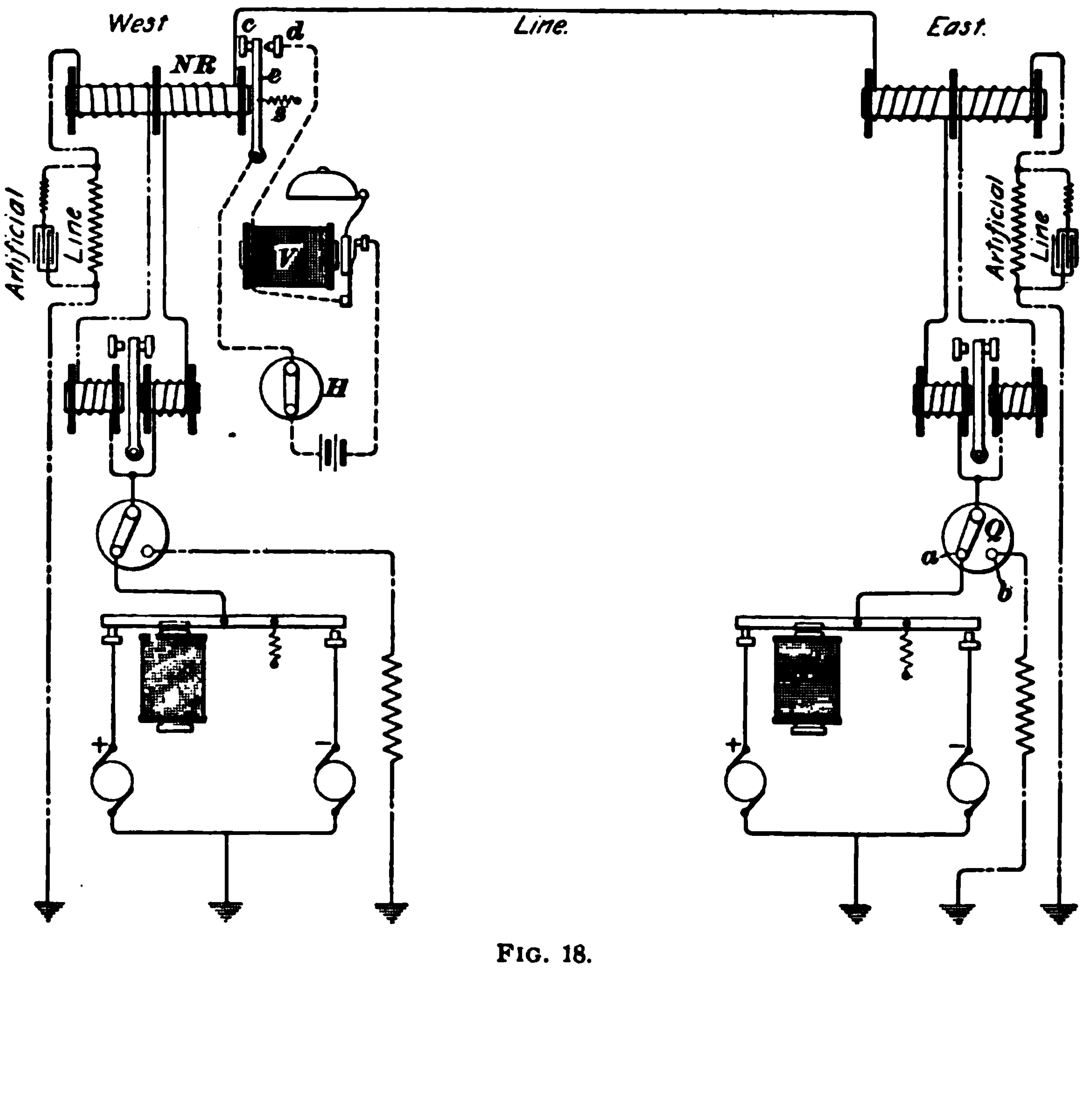


FIG. 18.

bell V are connected in the circuits, as shown at the west station. The connections will be the same at both stations, but only enough to explain the operation are shown. The spring s of the neutral relay is so adjusted that the armature will be held against the front stop c as long as the battery or dynamo at the distant east station is connected to the line. This is the case while the arm of the switch Q remains in contact with the button a. If the main battery or dynamo at the distant east station be disconnected and the circuit grounded by turning the arm of the switch Q to contact button b, the current from the west main battery or dynamo will divide equally through the two differential coils of the extra neutral relay. The magnetizing effect of one coil will be neutralized by the other and, consequently, the armature e will fall against the back stop d and cause the brating bell V to ring as long as the eastern operator allow the arm of the switch Q to remain in contact with b or until the western operator opens the local bell circuit by means of the switch H.

SIMULTANEOUS TELEGRAPHY AND TELEPHONY.

53. The transmission of telegraph and telephone messages over the same wire at the same time is called **simultaneous telegraphy and telephony.**

VAN RYSSELBERGHE METHOD.

54. The **Van Rysselberghe method** for the simultaneous transmission of telephone and telegraph messages over the same line was originated and developed by Mr. J. F. Van Rysselberghe, an official of the Belgian telegraph service. It is now being used both in Europe and America. Before describing the method of arranging the telegraph and telephone apparatus by which this simultaneous

transmission can be accomplished, it will be well to consider briefly some of the fundamental principles involved.

55. One of the difficulties to be overcome in attempting to telegraph and telephone simultaneously over the same wire is the prevention of telegraphic signals being heard in the telphone receiver. Unless this is done, much annoyance will be caused those using the telephone; besides, the secrecy of the telegraph will be destroyed. The wasting of the telephone currents in the telegraph instrument must also be avoided.

In a simple short telegraph circuit, the current will rise to its maximum value almost instantly when the key is closed and fall to zero almost instantly when the key is opened. A curve representing the current in such a circuit is about as shown in Fig. 19.

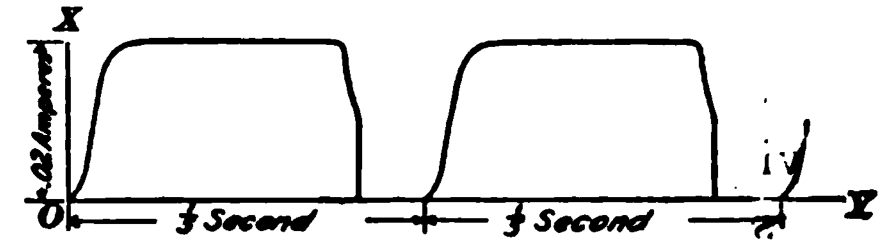


Fig. 19.

The time required for the current to reach its maximum value, even on an overhead line of 350 miles in length, is ordinarily less than one-fortieth the time required to make a dot. In telegraphing at the rate of 25 words a minute, which is equivalent to about 5 Morse signals a second, there would be, if means were not taken to avoid it, 10 intense clicks every second in a telephone receiver connected between the line wire and the ground, one of these being made every time the telegraph key was closed and another every time it was opened, due to the very rapid rise and fall of the relatively large telegraph current, which is about 100 times larger than the telephone current. If the telegraph current can be made to rise and fall gradually enough, the telephone receiver will not make any click. The accomplishment of this result has made possible this method of simultaneously telephoning and telegraphing over the same wire..

56. It is a well-known fact that the sudden rise and fall of a current in a circuit can be delayed, that is, made more

gradual, by increasing the inductance in the circuit. Furthermore, if in addition to the inductance coil, a condenser is connected from the line to the ground, the current in the line will rise and fall still more slowly. Hence, by using

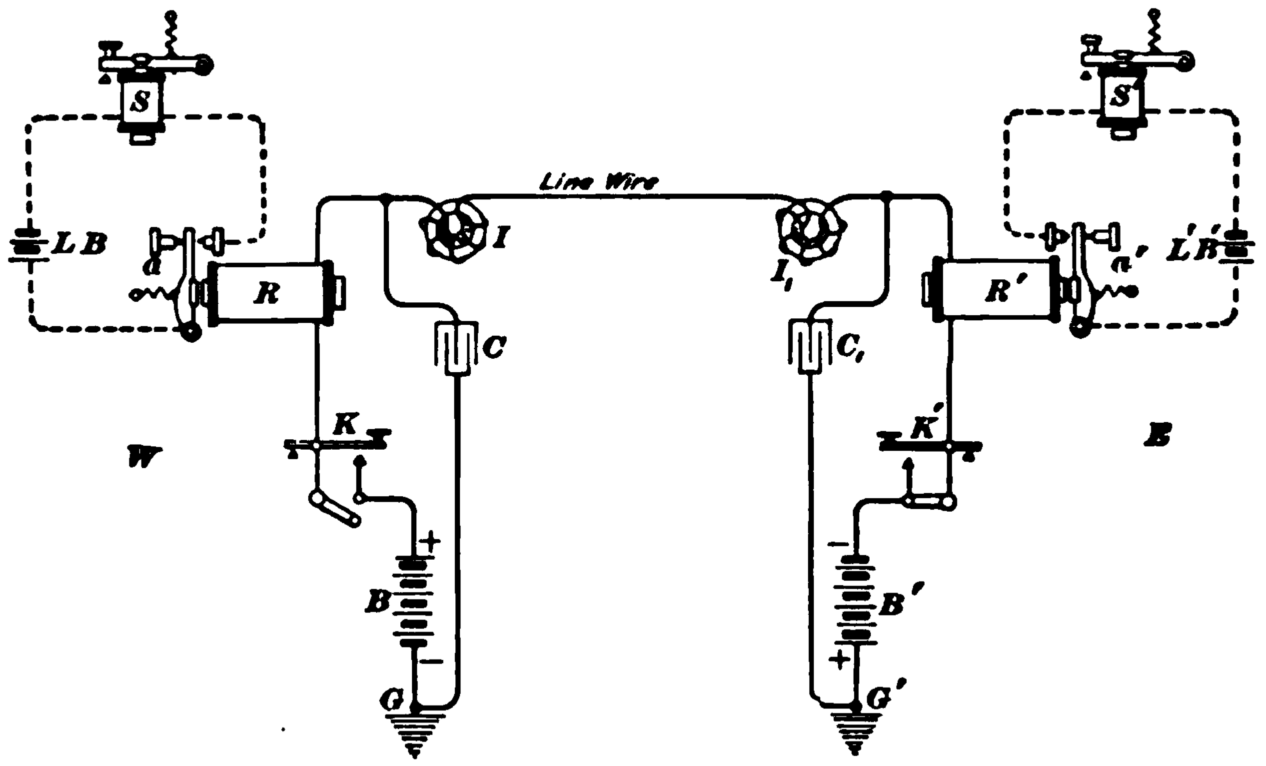


Fig. 20.

enough inductance coils and condensers, the current in the line may be made to rise and fall as slowly as desired. A simple telegraph circuit, with two inductance coils I and I_1, and two condensers C and C_1, connected in the circuit, is shown in Fig. 20.

The coils I and I_1 are called *impedance*, *retardation*, or *choke* coils, and are usually made by winding a large number of turns of insulated copper wire over a soft-iron wire core, the ends of the iron wire being brought together and overlapped, as shown in Fig. 21, so as to form a closed iron circuit for the magnetic lines of force. With a given number of turns of insulated copper wire and a given cross-section of iron, such a closed magnetic circuit will give a maximum inductance, causing a maximum opposition to a rapid rise or fall of the current. In making such a coil, it is of much more importance to have a large number of turns of copper wire and a good magnetic circuit of iron than to have a

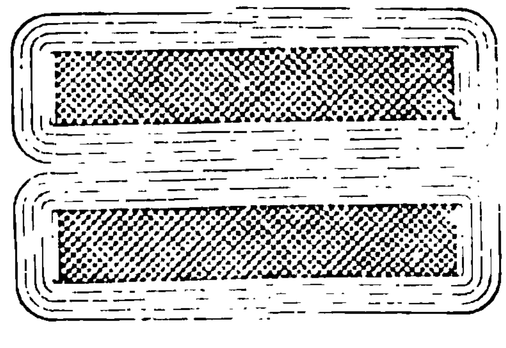


Fig. 21.

large resistance. In fact, the smaller the simple resistance can be kept the better, provided there are a sufficient number of turns. Low resistance and a large number of turns means a large coil, because large-sized copper wire must be used, and it becomes necessary to compromise in order to have neither too large a coil nor too high a resistance with a given number of turns. A choke coil of about 50 ohms resistance may be made by winding the one mentioned in Art. **68** with No. 31 B. & S. copper wire.

57. When the key *K* in Fig. 20 is closed, the inductance of the relay *R* and of the impedance coil *I* will act as a barrier to the increasing current and will prevent it from attaining its maximum strength as quickly as it would if the impedance coil *I* was not in the circuit. The greater the inductance in the circuit, the slower will the current increase and decrease. Furthermore, the condenser *C* must be fully charged before the current in the line can reach its maximum value. As fast as the current is able to get through the relay *R*, it first tends to charge the condenser *C*, and as the condenser becomes more and more nearly charged to its full capacity, more current will flow through the coil *I*, which also impedes any rapid increase in the current. The increase in the strength of the current in the line wire is thus made to take place more slowly than it would without the condenser and the impedance coil.

On opening the key *K*, the condenser *C* tends to discharge its current through the coil *I* into the line in the direction of the original current, thereby tending to prolong the current in the line and causing it to decrease more gradually. The combination of condensers and impedance coils thus opposes any rapid change in the strength of the current, and the current curve can be made to approach that shown in Fig. 22 by using the proper amount of inductance and capacity.

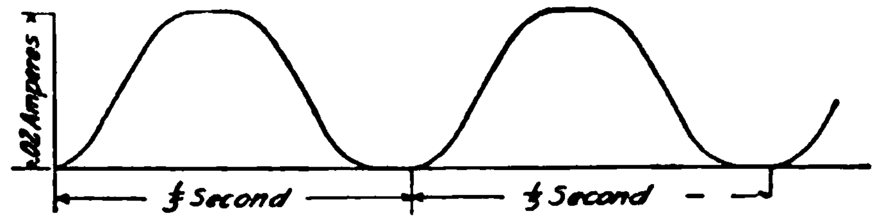


FIG. 22.

T. G. II.—18

58. At the rate of 25 words a minute, there would be about 5 dots and spaces, or 5 curves, like the one shown in Fig. 22, a second. The induction coils and condensers will interfere with telegraphing at a high speed, and especially with rapid automatic systems, because the signals would be of such a short duration that there would not be time for the current to rise or fall through a sufficient range to properly operate the relays. Moreover, even if suitable relays or other instruments could be used, such rapid signaling would interfere with what we are striving for, namely, to telephone as well as to telegraph over the same line. About the lowest audible sound is produced by 16 complete vibrations per

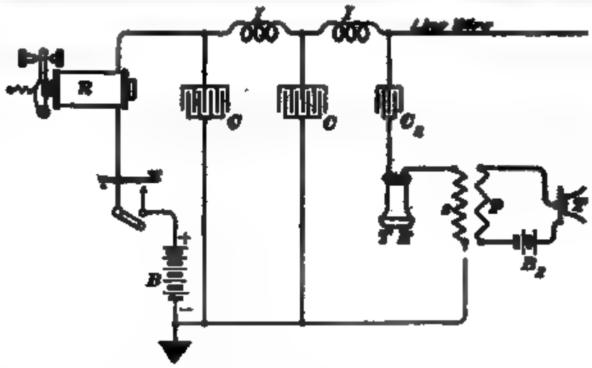


FIG. 23.

second. Therefore, an undulating current that changes at such a slow rate that it would never cause the diaphragm of a telephone receiver to move as fast as it would be moved by a current having a frequency of 16 periods per second, would produce no sound, not even a single click, in the receiver.

Now, if a telephone receiver TR and the secondary winding s of the induction coil were connected between the line and the ground, as shown in Fig. 23, but without the condenser C_2, more or less of the telegraph current would go through the receiver circuit to the ground in preference to passing through the line and the distant-office instruments. Even if this current produced no sound in the receiver, it would still be necessary (in order that the telegraph signal

made at the sending station shall affect the relay at the receiving station) to prevent the flow or leakage of the telegraph current through the receiver. To accomplish this, the condenser C_2 is connected between the receiver and the line. The condenser will not allow a continuous current to pass through it, because its resistance to such a current is practically infinite. The condenser charges and discharges very slowly when telegraph signals are being sent, thereby causing the receiver diaphragm to move in and out very slowly, but the rate of change of the current in the receiver is not great enough to cause an audible sound.

59. It has been shown that the telegraph signals do not affect the telephone receivers. It yet remains to be shown that the telephone currents sent from one end will operate the telephone at the other end, but will not interfere with the telegraph signals sent from either end.

In ordinary conversation, the average frequency of the sound waves is at least 300 complete vibrations, or periods, per second. By talking into a telephone transmitter, therefore, an alternating electromotive force is generated in the secondary winding of the induction coil, the average frequency of which is at least 300 periods per second. This rapidly alternating electromotive force will charge and discharge the condenser C_2, thereby producing in the line wire an alternating current similar to that in an ordinary telephone line. In Fig. 24 is represented such a current wave as might be produced in the line wire by the simplest sound waves having a frequency of 300 periods per second. Let the curve A in Fig. 25 represent the slowly increasing and decreasing telegraph current, and the curve B the rapidly alternating telephone current. In the line, these two will be superimposed on each other, producing a resultant curve of the form shown at C.

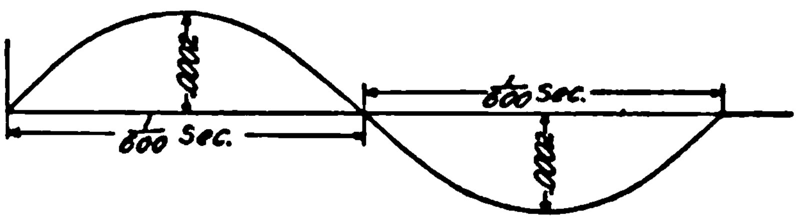


FIG. 24.

When both the telephone and telegraph are in simultaneous

operation, the telegraph current causes the diaphragm of the receiver to move in and out through a relatively large amplitude, but too slowly to make any sound. At the same time, it will vibrate very rapidly through a very small amplitude, because the telegraph current will have its strength very rapidly but very minutely increased and decreased by the telephone current. The variation in the strength of the current is enough, nevertheless, to increase and decrease the pull of the magnet on the diaphragm sufficiently to produce sound waves. One vibration is thus superimposed on the other, and the diaphragm vibrates, or trembles, very rapidly as it moves slowly in and out as the telegraph current slowly increases and decreases, and it reproduces the words spoken at the distant transmitter, but the telegraph current produces no sound.

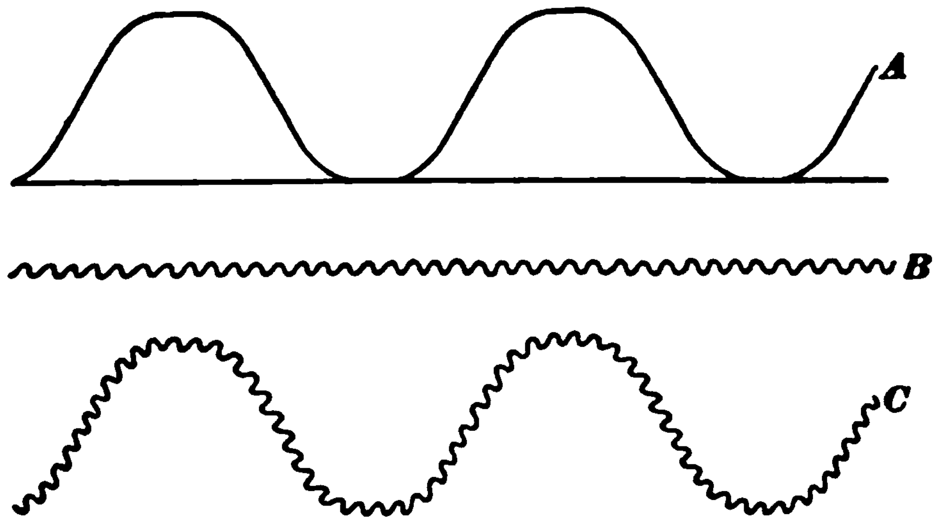


FIG. 25.

60. The question might arise as to why the telephone current does not go to the ground through the telegraph apparatus at the end where it is generated and interfere with the telegraph signals, instead of flowing through the long line wire to the distant telephone. In the first place, even if all the telephone current did go through the home telegraph apparatus, it would not affect the signals, for the telephone current is probably less than one-hundredth as large as the telegraph current, and its effect on the relay would not be apparent, as is evident from curve C, Fig. 25. Moreover, practically the whole telephone current will go over the line and through the distant receiver, for the following reason: It is a well-established fact that a circuit containing inductance offers more opposition, or impedance, as it is called, to the flow of an alternating current than the simple

resistance with which it opposes a direct current, and this opposition increases very rapidly as the frequency increases. For instance, a certain impedance coil, with a resistance of 500 ohms and an inductance of 8 henrys (for a current of .013 ampere), offers an impedance of 15,128 ohms to an alternating current whose frequency is 300 periods per second. This impedance is over 30 times as large as the simple resistance.

The impedance of the ordinary 250-ohm secondary coil may be as much as 4 times its resistance, but the condenser in series with it tends to reduce the impedance of this circuit, and consequently the impedance of the telephone circuit, including the receiver, the secondary coil, and the condenser, is probably not over 1,000 ohms. An induction coil having a lower resistance secondary, such as the 14-ohm coil used by the Bell Telephone Company on some of their long-distance lines, would be better in this case. In circuit with the impedance coil there is also the relay, so that the total impedance of the apparatus at one end of the line circuit shown in Fig. 20 is probably more than 50 times as great as that of one receiver circuit. To insure more satisfactory results, two impedance coils and two condensers are generally used at each end, as shown in Fig. 23, thus compelling practically all the telephone current to pass through the line and the distant telephone circuit, because the latter offers so much less opposition to its passage than the impedance coils and relays.

61. The **complete arrangement** of the telegraph and telephone apparatus is shown in Fig. 26. It is sometimes advantageous to connect a condenser of 1 or 2 microfarads capacity around the telegraph key and relay, as shown by the dotted lines at station *2*. This figure gives a complete diagram of connections for one complete metallic telephone circuit and two telegraph circuits over one pair of line wires, the ground being used as a return for the two telegraph circuits.

If a completely closed magnetic circuit of good soft iron

is used for the impedance coils o, enough turns of insulated copper wire to make 50 ohms have been found to be sufficient for each coil. Where only an iron core instead of a complete iron current is used, 500 ohms are often necessary. The condenser in the telephone circuit has a capacity of 3 microfarads; the condensers connected between the impedance coils and the ground have a capacity of 6 microfarads. If desirable, an ordinary telephone annunciator may be used, as shown at D, station *2*, in place of the bell shown at station *1*, and a push button k may be arranged, as shown at station *2*, to short-circuit the secondary winding S of the induction coil while listening. The push button k must be released while talking. This push button is not desirable, because if it is held closed while talking, the person listening at the other end can hear nothing. However, it may improve the working enough to warrant its use.

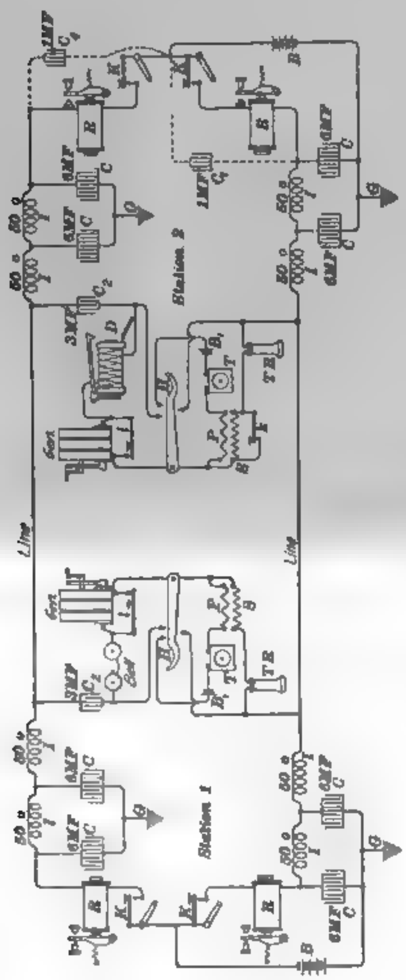


FIG. 26

62. The push button l is arranged to normally short-circuit the generator armature in order to cut its resistance

out of the circuit. When the generator handle is turned to call up the distant station, this push button should be pressed, in order to open the short circuit around the generator. Most generators have an automatic device that accomplishes the same purpose when the handle of the generator is turned. *H* is the ordinary hook switch. When the receiver is on the hook, the bell and generator are connected through the condenser C_2 across the two line wires, the circuit containing the primary winding *P* of the induction coil, the transmitter *T*, and the transmitter battery B_1 is open, and the circuit containing the telephone receiver *TR* and the secondary winding *S* is short-circuited. When the receiver is removed from the hook, the bell and generator are short-circuited, the local transmitter circuit is closed, and the short circuit around the receiver and secondary is opened, leaving this latter circuit closed through the condenser C_2 across the two line wires.

63. Over one line wire it is practical to send simultaneously one telegraph and one telephone message, no second line wire being at all necessary. To do this the following changes would be made in Fig. 26: The two main-line telegraph batteries *B*, *B* and the lower ends of the two telephone sets should be directly grounded, and the two lower telegraph sets (one at each end, including the two adjacent impedance coils and the two condensers) and the lower line wire should be omitted.

CAILHO'S METHOD.

64. M. Cailho, a Frenchman, has devised a method whereby the two line wires that form one complete metallic telephone circuit are connected in parallel for one side of the telegraph circuit, the ground being used as the other side of the telegraph circuit. In this method, which is much simpler than that of Van Rysselberghe, only one

instead of two telegraph messages can be sent over the two wires.

65. The arrangement devised by M. Cailho is shown in Fig. 27. A coil consisting of two identical windings D and E of insulated copper wire, each having exactly the same resistance and the same number of turns, is wound on the same soft-iron wire core. This arrangement is similar to the bridge duplex telegraph system used on submarine cables. The telegraph currents divide at the point f into two equal parts, since the two paths have equal resistance,

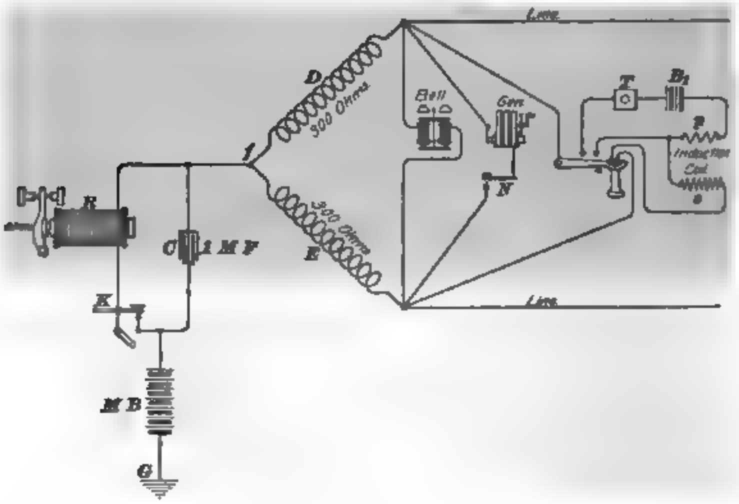


FIG. 27.

and pass through the two windings in opposite directions, so that the two coils tend to magnetize the iron core equally but in opposite directions; and, consequently, the self-induction will be practically zero and the impedance to the telegraph current will be no larger than the resistance. For the telephone currents, however, the case is different. They will have to pass through the two halves D and E in the same direction and, consequently, the impedance offered by the coil to the telephone current will be very large, thus practically forcing all this current through the telephone

where it belongs. Thus the coils prevent the telephone currents from passing through them, but as they add only one-half the resistance of one coil to the telegraph circuit (since there are two coils in parallel), they do not interfere appreciably with the telegraph signals.

66. M. Cailho has successfully used coils of lower resistance at D and E, but the induction was made high. Morse relay magnets having a resistance of 500 or 600 ohms, or 1,000-ohm telephone-bell magnets, as will be shown in Pfund's system, may be used in place of the special coils. In this case the point f will be the junction of the two coils of the relay magnet. This method has the advantage in that condensers are not absolutely necessary, and the extra apparatus needed is very much simpler than in Van Rysselberghe's method. Furthermore, the talking qualities of the telephone are not interfered with in the least and ordinary telephones may be used. What are known as *bridging telephones*, that is, telephones with bells of high resistance (at least 1,000 ohms) permanently connected across the two line wires, should be used. N represents a manual or automatic device that normally keeps the generator circuit open. When the generator handle is turned, the circuit must be closed at N, either automatically or by hand. T and B_1 represent the telephone transmitter and battery, respectively, and p and s the primary and secondary winding, respectively, of a telephone induction coil. If care is taken that the two halves D and E of the coil have exactly the same resistance and number of turns and that the two line wires are reasonably equal in resistance, clicks in the telephone will not seriously interfere with talking, although they may sometimes be heard. However, if the clicking is found to be objectionable, it may be almost, if not entirely, obliterated by connecting a condenser C of one or two microfarad capacity around the telegraph relay and key at each station. This system has been quite extensively used in France. The fundamental principle on which this method depends is also used in the two following systems.

SY[illegible]M USED BY TELEPHONE COMPANIES.

67. The Pacific States Telephone and Telegraph Company as well as other telephone companies use a simultaneous telegraph and telephone system quite extensively between important long-distance telephone exchanges. One operator signals another by telegraph to answer on that particular telephone line and again "rings off," that is, notifies the other operator when the subscribers have finished their conversation, without ringing any of the subscribers' telephone bells. This plan avoids ringing a subscriber's bell when he is not wanted and without the use of an extra wire for that purpose alone.

This company uses 600-ohm *retardation*, or *choke*, coils, as they are also called, for the coils D and E in Fig. 27, but no condenser at C. They arrange intermediate stations as shown in Fig. 28, in which I, I, I, I are 600-ohm retardation coils. In each line is inserted a condenser C, C'; an ordinary bridging telephone is connected across the two line wires. It will be noticed that, except where an intermediate telegraph instrument is cut in, the four retardation coils are the only pieces of apparatus that are required, besides the regular telephone and telegraph instruments. Even for an intermediate station only two condensers and four retardation coils are necessary. The arrangement of the intermediate telegraph station, as shown in the Pfund method, is probably superior to the arrangement shown here.

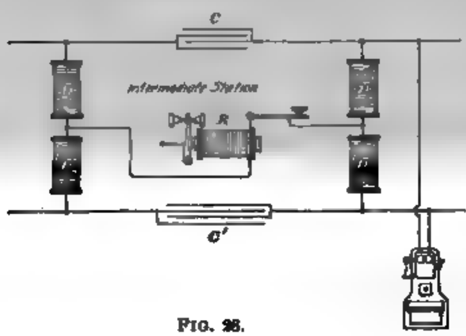


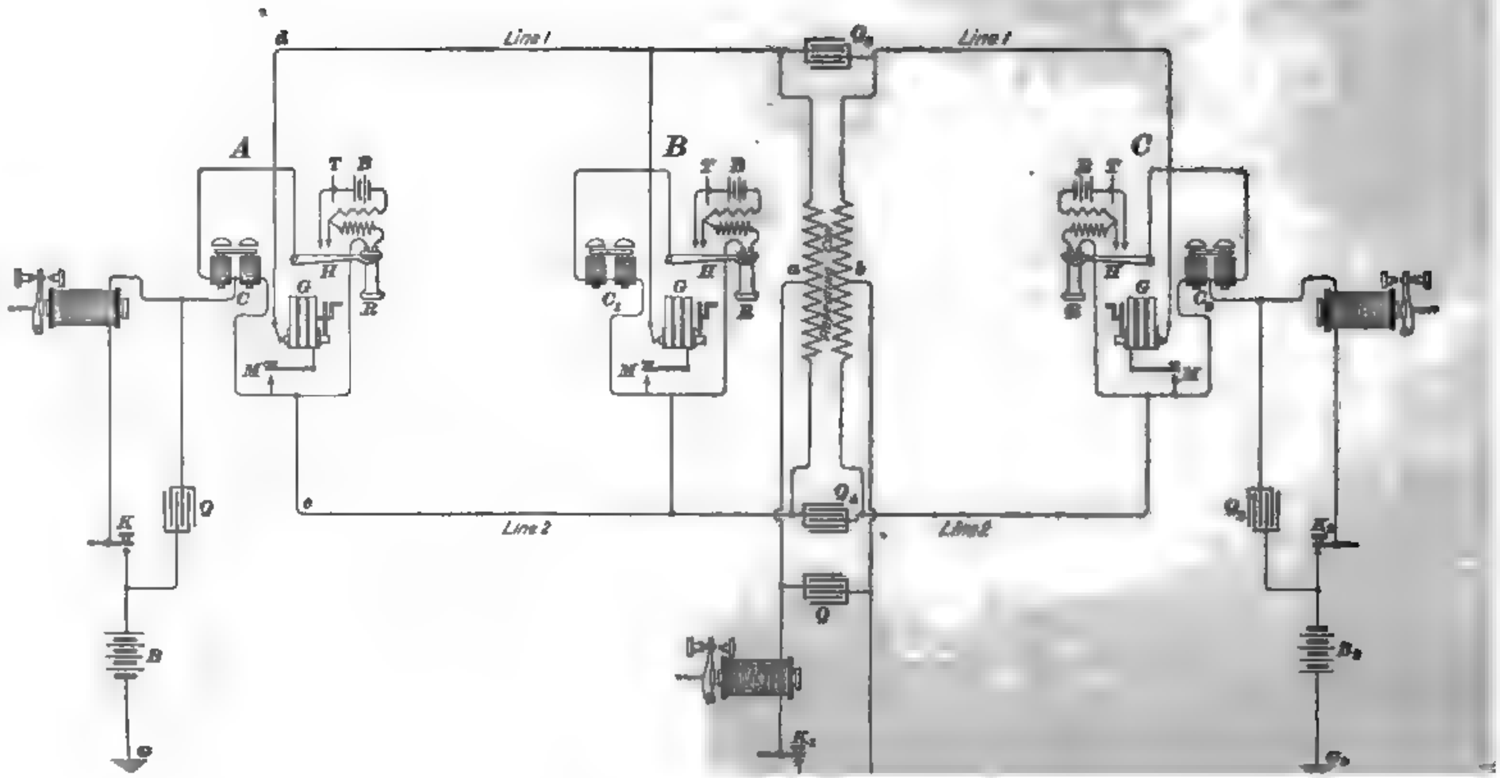
FIG. 28.

68. Dimensions of Choke Coils.—Two or three different styles of choke coils are used. The one used the most has an iron core $\frac{5}{16}$ inch in diameter, a length between

heads of $3\frac{3}{16}$ inches, and is wound to a depth of about $\frac{1}{2}$ inch with No. 36 B. & S. copper wire, giving a resistance of 600 ohms. The whole is iron clad, that is, closed by an iron cylindrical shell $\frac{1}{16}$ inch thick and by two iron end plates. The iron parts are firmly fastened together by a screw at each end. The capacity of the various condensers does not exceed 3 or 4 microfarads each. The induction coil is the one generally used by this company in its bridging telephones having 1,000-ohm bells and solid-back transmitters. The secondary winding of the induction coil has a resistance of 14 ohms and the primary winding a resistance of $\frac{1}{2}$ ohm.

PFUND SYSTEM.

69. Pfund's method for telephoning and telegraphing over the same wires at the same time is shown in Fig. 29. The two line wires form the two sides of the telephone circuit. For telegraphing, however, the two line wires are used as one side and the earth as the return. Three stations A, B, C are shown, A and C being terminal stations and B an intermediate station anywhere between the other two. The arrangement of the telephone and telegraph apparatus is clearly shown. There are in addition to the usual apparatus, a number of condensers Q, and at the intermediate station a so-called *repeating coil*. The repeating coil is a form of telephone induction coil having the same number of turns in the primary and secondary windings and a closed magnetic circuit of iron. The polarized or *magneto* telephone bells C, C', C_2, as they are called, are wound so that they offer a very high impedance to rapidly alternating currents, such as generated in the telephone circuit; consequently, practically none of the telephone current will pass through these bells or through the relays. Bells wound to a resistance of at least 1,000 ohms should be used. The repeating coils and the condensers Q_3 and Q_4 are used only where it is necessary to insert an intermediate telegraph station.


A
B
C
Line 1
Line 1
Line 2
Line 2
T
B
H
G
R
C
M
K
Q
B
G
C_1
Q_3
Q_4
a
b
e
Q
K_1
Q_5
K_2
B_2
G_2

The telephone current will pass from A to C, partially through the condenser Q_3 and Q_4 and partially by induction through the repeating coil. The telegraph current from A to C will pass from the battery B, through the key and relay, to the middle of the winding of the bell C. There it will divide equally, one half passing through line *1* and the other through line *2* to the point a, where the two halves unite and pass through the relay R_1 and the key K_1 to the point b, where the current again divides equally, half flowing through line *1* and half through line *2* to the center of the bell C_2. They again unite at this point and flow through the relay R_2, the key K_2, and the battery B_2, to the ground G_2, returning through the ground to station A. Since this telegraph current flows equally through lines *1* and *2*, it will produce no difference of potential between such points as d, e, and consequently no disturbance will be produced in the telephones connected across these points; thus none of the telephone instruments will be disturbed by the telegraph currents. Moreover, the telephone current is not large enough to cause any trouble in the relays, even if it could go through them. The telephone current will be confined to the two line wires and will not flow through the relays and the ground, because the bells and relays offer a much greater impedance to the talking current on account of its fluctuating character than do the line wires, the condensers Q_3 and Q_4, or the repeating coil.

The condensers that are connected across the keys and relays not only reduce sparking at the keys, but also prevent a very rapid rise or fall in the strength of the telegraph current in the line wire. The inductance of the bell C also tends to reduce the rapid rise or fall in the strength of the telegraph current. In this system we are able to carry on conversation over two line wires between any of the stations connected by them, and at the same time to telegraph over the same circuit, using for the latter purpose the two line wires as one conductor and the earth as the return. No special apparatus is required; the repeating

coil and the high impedance bells are the same as regularly used in telephone systems.

70. In Van Rysselberghe's method, one telephone and two telegraph messages can be sent simultaneously over one pair of line wires, using the earth as a return path only for the two telegraph currents; or, by using the earth as a return for the telephone as well as for the telegraph current, then over a single wire one telephone and one telegraph message may be transmitted simultaneously. In Cailho's and Pfund's methods, however, two line wires are required for one side of one telegraph circuit, and hence only one telegraph and one telephone message can be transmitted simultaneously over two line wires, using the ground as a return for the telegraph current only. In these systems, high-resistance relays (150 ohms) should be used, and half the total number of cells necessary for operating the telegraph instruments had better be placed at each end, the two batteries being in series, of course, with each other.

EDISON PHONOPLEX.

71. The **Edison phonoplex system** is a well-known method of transforming a single Morse wire into a duplex circuit on which it is possible to send two separate messages from one station, or to send one message and receive another at the same time. It is thus an excellent emergency system, meeting the requirements of special occasions and doubling the number of circuits where wires are scarce. It is especially invaluable to the railroad service, where the number of wires is usually limited, since it provides an extra circuit that is available at all times.

72. The **principle** of the phonoplex system may be readily understood by the aid of Fig. 30. Two end stations are here represented as equipped with a Morse and phonoplex

set. The Morse relays and keys are bridged by condensers. A coil of wire *M*, wound on an iron core so as to have a high inductance, is called the *magnetic coil*. *C* is a condenser of small capacity bridged around the magnetic coil *M*. Its purpose is to quicken the impulses sent out over the line.

In order to explain the principle on which the phonoplex works, an ordinary walking-beam pole changer *Pt* is shown here. A resistance *d* of about 10 ohms is connected between the battery *Pb*, which we will call the phonoplex battery, and the contact *p*. The pole changer itself is operated by the local battery *L B* and the key *Pk* in the usual manner. The receiving instrument, or *phone*, as it is called, consists of an elongated horseshoe magnet, having wound on each of its terminals a small coil of insulated copper wire. Above the poles is a large diaphragm. So far the phone resembles a double-pole telephone receiver. In addition, however, there is a split steel ring *n* resting on the diaphragm, but so arranged that it can move freely up and down on a vertical pin *m*. Each agitation of the diaphragm causes the steel ring to be thrown against the nut, producing an excellent imitation of the tone of a telegraph sounder.

73. Operation.—To comprehend the working of the apparatus, it will be necessary to bear in mind that the transmitter produces the effect of dots and dashes by opening circuits and not by closing them. Suppose that the key *Pk* is open; then a steady current of considerable strength will be flowing from the phonoplex battery *Pb* through the magnetic coil (which has a resistance of a few ohms only) and the stop *o*.

If the key *Pk* is now closed, this current will be abruptly broken at *o*, causing quite a high counter electromotive force to be developed in the magnetic coil, due to its high self-induction; and since the circuit is open at *o* and *p*, there is no other outlet except along the line for the electrical impulses at this instant; they must, therefore, travel along

the line. The phone at the distant end responds to thes
impulses, but the impulses are comparatively feeble i

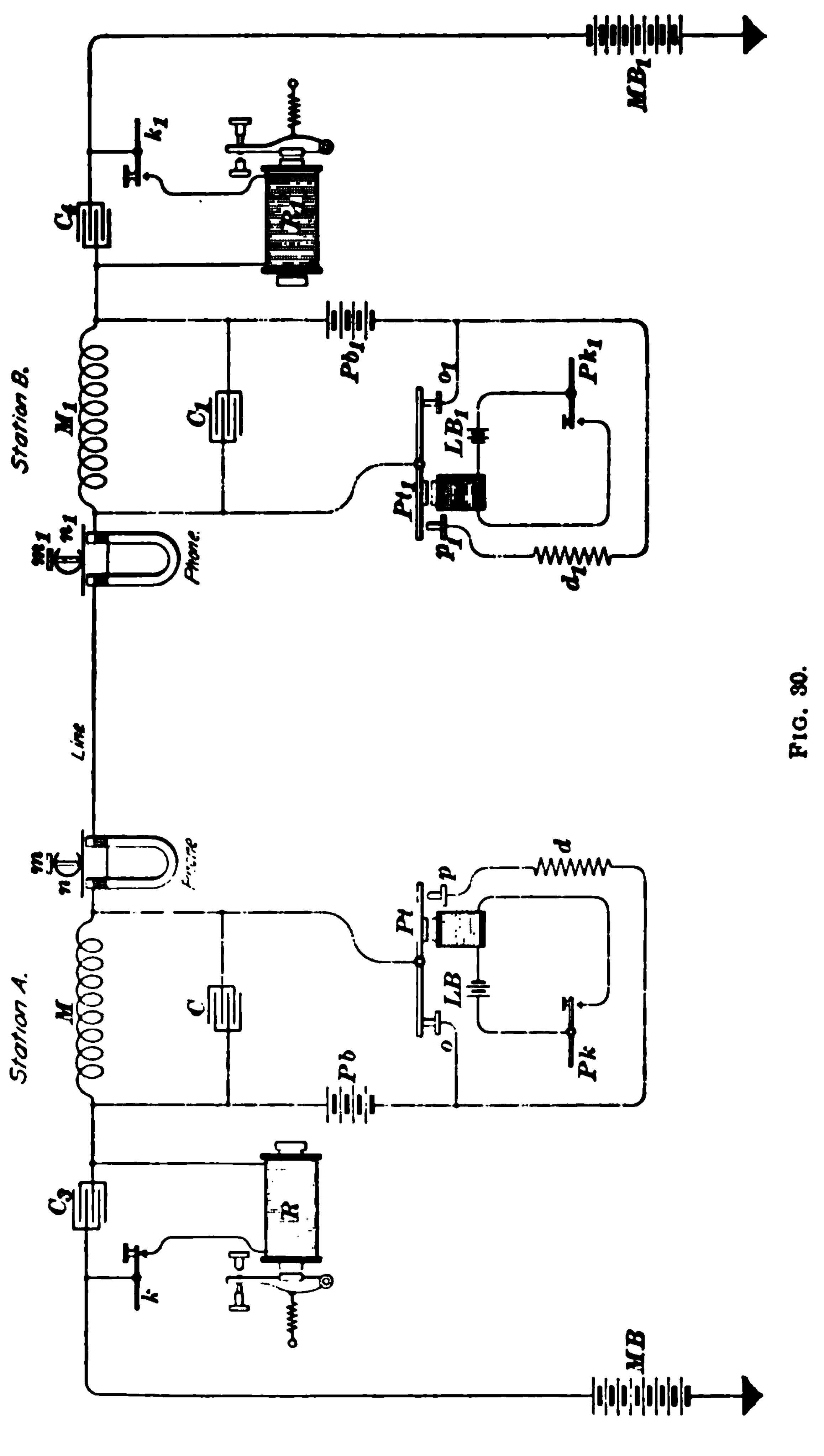


FIG. 30.

comparison with the Morse current; moreover, they are changing very rapidly in strength and hence will pass through the condenser C_1, around the magnetic coil M_1, and

through the condensers C_2 and C_3 instead of the relays R and R_1, and thus will not operate the relays. The sound made by the phone corresponds to the down or front stroke of an ordinary sounder. A moment later the circuit is closed at p, and although impulses are doubtless set up again in the magnetic coil, they can now expend themselves in the closed local circuit and do not produce any impulses of appreciable strength in the line circuit. The current flowing is not as strong, on account of the extra resistance d which is now included in the circuit with the phonoplex battery, as the current that flowed when the lever touched o.

When the key is released, this smaller current will be abruptly broken at p, and will develop in the magnetic coil a counter electromotive force of somewhat less intensity than when the key was closed. These impulses, for the same reason as given before, will travel along the main line, but will produce a sound less intense, however, than before, and so will resemble the sound produced by the back stroke of an ordinary sounder.

A moment later the circuit will again be closed at o, but the impulses that are developed in the magnetic coil will not flow out over the main line, but will expend themselves in the closed local circuit. Thus the down and up, or front and back, strokes of an ordinary sounder have been closely imitated and the system is ready for the production of another signal.

74. The resistance of the extra coil d—which is included in the battery circuit in one position of the transmitter Pt in order to produce an effect in the phone resembling the up and down stroke of an ordinary sounder—is not more than 10 ohms. The condenser C intensifies the impulses sent out by the coil M. The key Pk is not intended to merely open and close the circuit of the battery Pb through the coil M, but rather to cause impulses of two different intensities to be sent through the main line. Since the phone is an instrument that produces a sound only when

the current passing through it is rapidly changing in strength, the slowly changing Morse current will not operate it. The phone is adjusted by means of the screw a

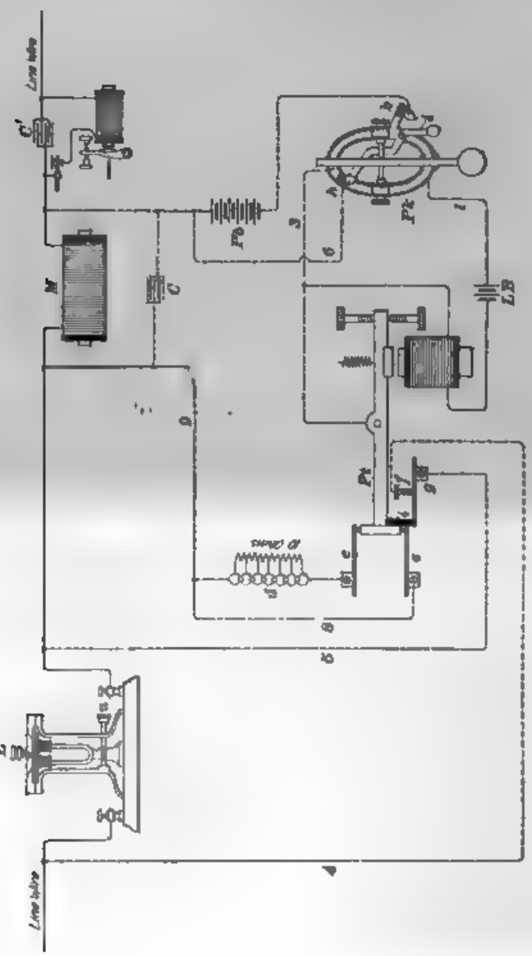


FIG. 31.

Fig. 31, so that the diaphragm is beyond the influence of the comparatively steady Morse currents, but is still within the influence of a rapidly changing current.

75. Practical Arrangement.—In Fig. 31, the complete and practical arrangement at an intermediate station is shown. The connection at the terminal station will be practically the same. This figure is lettered as far as possible like the preceding one.

The key *Pk* is slightly different from the ordinary key. The contacts *b* and *h* are insulated from the base or framework of the key. The bent lever *l* is permanently connected with the base and, consequently, to the wire *3*, which is also permanently connected to the base of the key. The wire *1* is connected, as usual, to a platinum point that is insulated from the base. When the bent lever *l* is turned to the left, which is called the *closed position*, the phonoplex battery *Pb* is left open at the point *b* and the magnetic coil *M* is short-circuited through the wires *9*, *8*, spring *c*, transmitter lever, wire *3*, base of key, the bent lever *l*, and wire *6*. Thus, in this position of the bent lever, the phonoplex transmitting apparatus is practically cut out of the circuit. The phonoplex battery is left open for the reason that it is of low resistance and depreciates rapidly when left on closed circuit. The magnetic coil *M* is short-circuited when not in use, so as to keep its resistance out of the main line.

76. Transmitting Position of Key Lever.—When the key is opened, that is, when the bent lever *l* is pushed to the right so as to come into contact with *b*, the phonoplex battery is connected through *b*, the bent lever *l*, base of key, wire *3*, through the transmitter spring *c* or *c*, and the magnetic coil *M*. This position of the lever *l* opens the short circuit around the magnetic coil and throws it into the line circuit, and furthermore closes the circuit of the phonoplex battery *Pb* through the magnetic coil and the transmitter springs. This is done when the operator desires to send a message. If the key is now manipulated, the transmitter will make and break the current through the magnetic coil. The key has no ordinary circuit closer; consequently, the circuit through the local battery *L B* and the

transmitter magnet is open at all times, except when a dot or dash is being made.

77. Receiving Position of Key Lever.—When the operator wishes to receive, he throws the lever *l* to the left, which act corresponds to closing the ordinary key, but in this system the movement disconnects the local battery *L B* from the transmitter, leaves the phonoplex battery *Pb* on open circuit, and short-circuits the magnetic coil, thus allowing the phone to be more readily affected by the discharge from the distant magnetic coil. The same result could, of course, be obtained with an ordinary key and a pole-changing switch.

When the key *Pk* is depressed while the lever *l* is turned to the right, the local circuit is closed and the armature of the transmitter is attracted, thereby breaking contact at spring *e* and sending an impulse from the magnetic coil into the line. When the key is released, the armature of the transmitter is also released and the circuit is broken at the point *c*, thus sending another but weaker impulse into the line. This time, however, the impulse produces a less intense sound that corresponds to the back stroke of an ordinary sounder, thereby enabling the operator to distinguish the difference between the two and thus avoid getting a back-stroke effect. Wires *4* and *5* connected to the points *f* and *g*, respectively, short-circuit the phone when the circuit containing the transmitter magnet is closed.

78. An insulated piece *i* attached to the lower part of the lever of the transmitter permits the spring *g* to make contact with the screw *f* just before the circuit is broken at *e* as the armature lever of the transmitter is attracted, and then breaking contact at *f* after the circuit has been broken at *c* as the armature is released. The phone at the home office is thus silenced while the home office is working. It is arranged this way because the response of the home phone to local impulses would be very loud if it were permitted to work, and some difficulty would be met with when

the receiving operator desired to break. The small condenser *C* not only quickens the impulses and helps the incoming signals, but also prevents excessive sparking at the contact points of the springs *c* and *e*. The Gordon, Edison-Lalande, bichromate of potassium, or other good closed-circuit, low-internal-resistance battery should be used for operating the phonoplex and only 10 or 12 volts are required.

79. One advantage of this system over the Morse is that it is less likely to be affected by ordinary trouble on the wire. It will work readily across heavy escapes or when the phonoplex wire is grounded or crossed with some other wire. Even bad weather fails to affect the signals to any great extent. All Morse sets in intermediate offices are bridged with condensers and the operation of the relays does not interfere in any manner with the working of the phonoplex. It is adapted for use between intermediate stations or between terminal stations.

A serious objection to the system is the fact that only one circuit can be worked successfully on the same line of poles carrying a number of wires, such as is usually strung along a railroad. A companion phonoplex on a line of poles on the opposite side of the track is even impracticable, for the reason that the phonoplex impulses are so penetrating that their inductive effects extend far into the space around the wire; hence it is much better to arrange only one phonoplex circuit along a line of wires in any one given direction. The phonoplex system at least duplexes the capacity of the line, as it may be used between any number of intermediate stations, any two of which may carry on telegraphic communications independently of the Morse system. It has been successfully worked on wires already duplexed or quadruplexed. The construction and operation of this system is simple, and the ease with which it can be adjusted places it within control of an ordinary operator.

SUBMARINE TELEGRAPHY.

INSTRUMENTS.

80. Cable Transmitting Key.—In submarine-cable telegraphy, the double-current system—a current in one direction to indicate a dot, and a current in the opposite direction to indicate a dash—is invariably used. Cablegrams are now transmitted both by hand and by automatic transmitters. The hand key is shown at *K* in Fig. 37. It consists of two long spring levers, or keys, *a* and *b*; one is operated by the index finger and the other by the second finger of the right hand. One lever *b* is connected to the cable conductor or apparatus, the other lever *a* is connected to the ground *G*. The two levers normally press against the strip *s* which is connected to the zinc pole of the battery. The under strip *c* is connected with the copper pole of the battery. When the lever *b* is pressed down, it leaves the strip *s* and touches the strip *c*. The circuit may then be traced from the ground *G*, to lever *a*, strip *s*, negative pole of the battery *B*, through the battery to the strip *c*, lever *b*, and to the cable conductor or apparatus. Thus the copper, or positive, pole is connected toward the cable and the zinc or negative pole to earth; hence a positive current flows toward the cable. When the other lever *a* is pressed down, a negative current will flow toward the cable, and the student should now be able to trace out the circuit for himself. When both keys are pressing against the strip *s*, the line is connected directly to earth. This is a good feature, for it allows the cable to wholly or partially discharge whenever, in making a space between two succeeding signals, both keys touch the top strip at the same time. The rate of signaling is not over 20 to 30 words a minute where this key is used, because its manipulation is not so simple as that of the ordinary key used on land lines in the United States.

81. Very Sensitive Receivers Necessary.—In order to avoid the danger of injuring the insulating material

of a submarine cable, an electromotive force exceeding 40 or 50 volts is seldom, if ever, used. For this reason, and also on account of the large distributed electrostatic capacity of a long submarine cable, the current at the receiving end is very small, too small to operate any kind of electromagnetic relay. Consequently a more delicate receiving apparatus is necessary. Since it requires some time after the closing of the key at the transmitting end before the current at the receiving end has increased so as to have an appreciable strength, it is evident that the smaller the current that can be detected by the receiving instrument, the higher can be the speed of signaling.

At first reflecting galvanometers were used, the signals being read by the right and left deflections of the spot of light, a movement in one direction indicating a dot, and a movement in the opposite direction a dash. One man observed the deflections, and called them out, while another wrote the message upon paper. Then the siphon recorder, invented by Sir William Thomson, now Lord Kelvin, was used.

THOMSON SIPHON RECORDER.

82. The **Thomson siphon recorder** consists of a coil of wire suspended by a silk fiber between the poles of a magnet. The current passes through this coil and causes it to swing in one direction or the reverse, according to the direction of the current. This coil is attached to a glass siphon by a thread, thereby moving the recording end of the siphon across a paper tape as the latter moves along uniformly under the siphon. The upper end of this siphon dips into a vessel containing ink, and the lower end spurts the ink upon the paper that is drawn past the end of the siphon. The ink is charged positively, while the plate over which the paper passes is given a negative charge. Consequently, the ink is splashed upon the paper in a very fine stream of dots and a record is thus obtained of the movements of the coil.

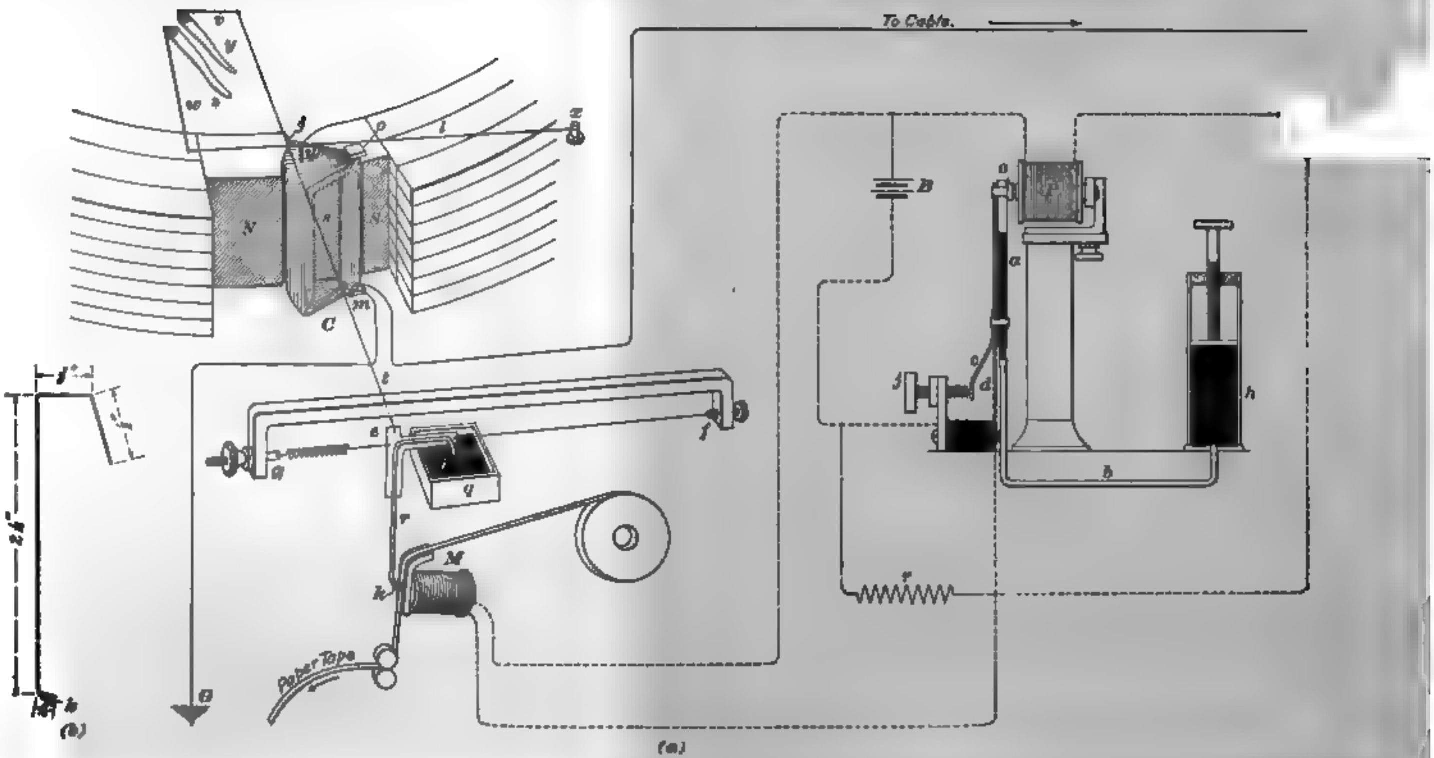


FIG. [illegible]

83. Mouse Mill.—The electrostatic machine used for charging the ink is called the **mouse mill.** At times there is sufficient moisture in the atmosphere to seriously interfere with the electrostatic charging devices; and for this reason the improved recorders now used, and which do not depend on the attraction of a positive charge for a negative charge of electricity to cause the ink to flow, but on a mechanical vibration of the siphon tube, are much preferable.

CUTTRISS RECORDER.

84. The principle of the **Cuttriss recorder** is shown in Fig. 32. *N* and *S* are the north and south poles of a powerful, compound, permanent magnet made up of a number of separate permanent magnets. The magnet maintains a strong field in the space between the poles *N* and *S*.

The pole piece *s* is curved outwardly at the end facing the pole *N* and the pole *N* is cut away, or hollowed out, to correspond, thus forming one convex and one concave cylindrical surface about *o m* as an axis. A narrow space is left between these two cylindrical surfaces on *N* and *s* and there is also an opening, or slot, between *S* and *s* from the front to a point slightly beyond the central line, in order that the coil *C* of fine wire may be put in place. The pole piece *s* extends through the coil *C* and one vertical side of the coil is free to revolve in the strong field between *N* and *s* about the vertical side *o m* as an axis.

The movable galvanometer coil *C* is very delicately pivoted and supported by means of jewel bearings at *m* and *o*, and above the coil is a plate or piece of iron (not shown in the figure) so disposed that, by attracting a small iron pin fastened to the coil, it reduces the pressure and, therefore, the friction at the bearings and causes the coil to apparently float in the magnetic field.

85. Glass Siphon and Support.—The fine glass siphon, which has an outside diameter of $\frac{1}{64}$ to $\frac{1}{100}$ inch, is

shown in Fig. 32 (*b*), the actual dimensions of one form being given. On the lower end of the siphon is fastened a small piece of iron *k* about $\frac{1}{8}$ inch long. This siphon *k i* is fastened, Fig. 32 (*a*), by wax or paraffin to a delicate holder *e* that is attached to the fine wire *g f*. By means of the screws *g* and *f*, between which the wire is stretched, not only can the right tension be given to the wire but also the right torsion for the siphon holder. To the top of the siphon holder *e* is fastened one end of a fine thread *t*, the other end being fastened to one end of a delicate spring *v*. At right angles to this thread is another thread *l* that is fastened rigidly at *x* to an adjusting screw and at the other end to a delicate spring *w*. The "tension fingers" *y* and *z*, as they are called, press with sufficient force ordinarily to hold them in place against the top of the plate upon which the device is mounted. They may be independently adjusted and made to exert whatever stress is required upon their respective threads.

The thread *l* passes through a slot or fork in a projecting piece *u* that is fastened to and moves with the coil *C*, the other thread *t* is fastened to the thread *l* at the point *j* where they cross each other. When the coil is deflected in the direction of the hands of a watch, it moves the thread *l*; this pulls on the thread *t*, and the spring *v* takes up the slack in the thread *t*. This causes the lower end *k* of the siphon to move toward the reader. The tendency of the torsion in the wire *g f* is to oppose the pull of the thread *t* and to move the lower end of the siphon away from the reader. When no current flows through the coil *C*, these threads, wires, and springs are in equilibrium and keep the end *k* of the siphon in its middle, or zero, position.

The higher leg of the siphon dips into a small trough *i* of specially prepared ink. Between its lower end and the pole of the electromagnet *M*, there is uniformly drawn by a suitable motor a continuous tape of white paper along whose middle, when the siphon is at rest, is traced a fine ink line, which may be called the "zero" line. The force tending to deflect the coil helps one or the other of the two

forces that were previously in equilibrium and consequently the end *k* of the siphon is moved across the paper tape; the direction in which the siphon moves depends on the direction of the current through the coil *C*.

86. Vibration of the Siphon.—The siphon is made to vibrate to and from the paper, as will be explained elsewhere, in order to avoid the friction between the end of the siphon and the paper tape, which would impede the movement of the delicately suspended coil. Thus the siphon traces a dotted instead of an absolute continuous line. This is necessary because otherwise the ink is liable to gather upon the end of the siphon in globular form, and either blur the record or cause it to stop recording. The ink well also is adjustable, and may be readily lowered in order that it may be removed.

87. Magnetic Vibrator.—The apparatus shown in Fig. 32 and used with the Cuttriss recorder to make the siphon vibrate may be called a **magnetic vibrator.** It consists of an arrangement of apparatus that will send pulsatory currents through the electromagnet *M*, the frequency of these pulsations being so regulated as to correspond with the natural rate of vibration of the siphon. Almost every vibrating body has a particular rate of vibration, depending on its length and various other conditions, at which it will vibrate most easily and freely. For instance, a tuning fork or reed of a certain length and having a certain pitch will vibrate readily at a certain rate, but it cannot be made to vibrate uniformly nor continuously at any other rate without the expenditure of considerable more energy. A glass tube *a* fastened to a spring or reed *d* has its lower end connected by a rubber tube with the cylinder *h* containing mercury. By means of a piston, the mercury can be forced to any desired height in the tube *a*, and thus the natural rate of vibration of the tube and spring may be varied as required. When a new glass siphon is adjusted on the apparatus, it is frequently necessary to change the

...te of vibration of the spring d and the glass tube a ... ond to the natural rate of vibration of the new ...

...en the contact spring c, which is attached to d, bears ...st the screw j, the circuit containing the battery B ...electromagnet P is closed and the magnet is energized. ... attracts the armature o fastened to the tube a and ... the circuit between c and j. The very high non-... resistance r which is connected between c and j ..., or at least reduces, the sparking when the circuit is broken between c and j; but its resistance is so high that it does not allow enough current to flow through P to cause the latter to attract or to hold its armature o. Consequently the armature is released, the circuit again closed between c and j, and the magnet P again energized. Thus a is kept vibrating uniformly and continuously, the principle being exactly the same as that used in buzzers and vibrating bells, and the circuit between c and j is thus opened and closed many times a second.

The opening and closing of the circuit containing the battery B and magnet M between c and j causes a rapidly pulsating current to flow from the battery B through the electromagnet M, causing it also to alternately attract and release the small piece of iron k fastened to the lower end of the glass siphon. Evidently the electromagnet M will have its circuit made and broken at the same rate as that of P.

88. Adjustments of Electromagnet.—The electromagnet M has an adjustable pole face constituting a table on which the paper rests as it passes beneath the recording point. As it is sometimes difficult to grind the recording end of the siphon so that its end will be exactly parallel with the face of the magnet, the pole piece of the magnet is made adjustable so that it may be turned until its face is parallel with the recording end of the siphon. The entire magnet M is supported so that it may be raised or lowered by means of an adjustable screw.

89. The general appearance of the Cuttriss recorder is shown in Fig. 33. It is practically the same as the figure already described, except that the wire $f g$ which supports

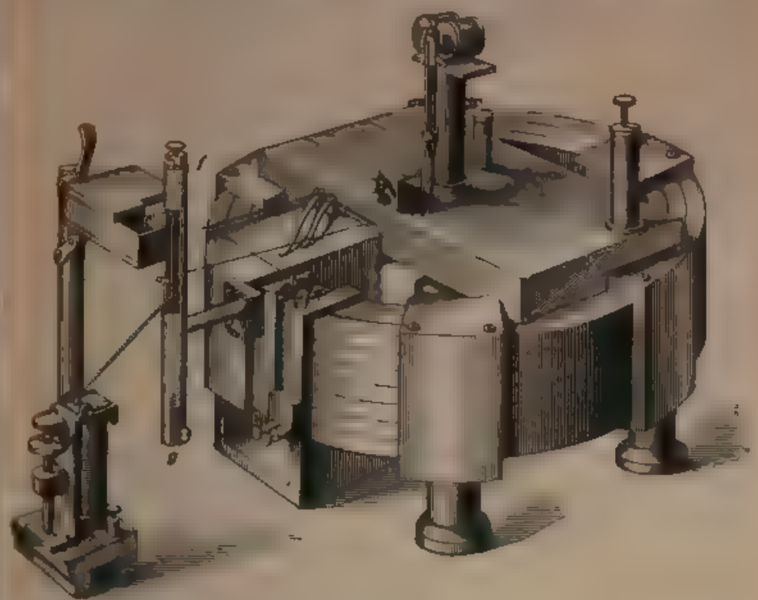
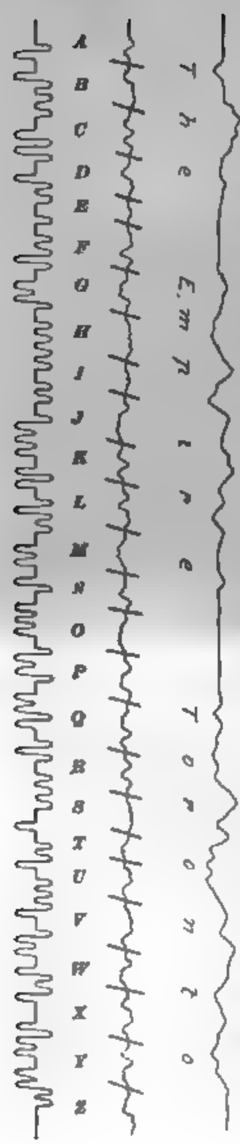


FIG. 33.

the siphon holder is vertical in this figure instead of horizontal, as shown in Fig. 32, and the siphon is necessarily shaped a little different to suit this construction.

CABLE ALPHABET.

90. The letters of the alphabet, figures, and other characters are formed by prearranged combinations of positive and negative currents that cause corresponding right and left movements of the recording end of the siphon. The letter "a" consists of one positive and one negative impulse, thus producing, to one facing the tape as it comes from under the siphon, one movement of the siphon to the left and one to the right; "b" consists of one negative and



(b) (c) (d)

FIG. 34.

three positive impulses, producing one movement of the siphon to the right and three to the left; and so on. On the paper tape these signals appear as being above or below the zero line which the siphon, when at rest, traces along the center of the tape. There is necessarily no return of the siphon to its zero line every time between impulses. In the case of impulses of opposite polarity, the siphon will usually cross the zero position or line, but in the case of several impulses of the same polarity, the curve will merely fall back a little and move a little farther away each time from the zero line.

The continental code is used on all submarine cables. If this alphabet is deliberately sent over a very short cable, it will be traced by a siphon recorder about as shown in Fig. 34 (*b*). If the letters are sent continuously one after another, the actual record made by the siphon recorder connected to a long submarine cable is shown in Fig 34 (*c*). Fig 34 (*d*), which is an accurate reproduction of a portion of a message actually transmitted over a transatlantic cable with the accompanying translation, will more clearly convey the character of the recorder signals. The message is translated and written down by the operator as the tape glides along in front of him.

91. Automatic Submarine-Cable Transmitters.—Sending by means of the hand key is the method

most generally used on submarine cables, but it is now being superseded by the automatic transmitter. The accuracy and speed of the working is thus greatly improved, for by this mechanism is obtained the utmost uniformity of signal with a speed and tirelessness unattainable by hand. By the use of the automatic transmitters, a speed of 40 or 50 words a minute may be reached on transatlantic cables. The Cuttriss, Willmot, and Muirhead automatic transmitters are used by the various cable companies. The Cuttriss is used in the United States. The Crehore and Squier sine-wave transmitter, which is suitable for use on submarine cables, as well as on land lines, will be described in connection with the sine-wave system.

CUTTRISS AUTOMATIC TRANSMITTER.

92. The principle of the **Cuttriss automatic transmitter,** whereby the positive and the negative impulses that are sent to the line or cable are controlled, may be explained by means of the diagram of connections shown in Fig. 35. *C*, *D*, *E*, *F*, and *B* show the ordinary arrangement of a cable key and the main battery. *G*, *H* are electromagnets, normally on open circuit, for operating the levers *C*, *D*. The so-called "trailers" *o* and *p*, under which a punched paper tape is drawn, are necessarily light and delicate; in order to keep their contacts in good condition by preventing the occurrence of sparks at *m* and *n*, the circuit is broken at *h* by means of the spring bar *j* and a cam *i* before the trailers open the circuit at *m* or *n*. The sparking is thus confined to the single contact at *h*, which may be made of substantial form and easily renewed and repaired. The spark may also be reduced by the use of a high non-inductive resistance *r*, which forms a shunt around the contact points.

93. A view of the Cuttriss transmitter is shown in Fig. 36. It is lettered the same as Fig. 35. On the shaft

levers, pivoted side by side in an insulating block c, and having in their ends pins with points beveled on the under side, as shown, and lying directly over the lines of perforations in the wheel G. There are several springs to keep the paper tape that runs over the wheel G pressed against the surface of the wheel, and to furnish guides through which the pins on the ends of the trailers may readily move up and down, but cannot move sidewise out of line of the holes. Each trailer has a spiral spring f, which tends to make the pin enter the indentations on the surface of the wheel G. The paper tape K is made with a central line of equidistant perforations. It is prepared for the transmitter by a suitable perforating machine that makes two lines of perforations on opposite sides of the central lines of perforations. The Wheatstone perforator, which will be described in connection with the Wheatstone automatic system, may be used by merely replacing certain round punches with square punches. The side on which the perforations are made depends on the direction or polarity of the impulses that they are designed to transmit, but every perforation is exactly in line with one of the central perforations. The pins in the wheel G enter the perforations in the center line of the tape and so draw along the tape when the wheel rotates.

94. When the motor that revolves the shaft t continuously and uniformly is started, both wheels W and G are rotated intermittently, the period of rest being so timed as to occur when the pins on the lower ends of the trailers are opposite, that is, in line with the pins projecting from the surface of the wheel G. If there is no perforation in the paper under either pin, they are prevented from dropping down; but whenever a perforation comes under one of the pins, it passes through the paper and causes its lever to make contact with m or n. On the shaft t is fixed a sleeve i having a raised portion that serves as a cam to raise the bar j, thus causing j to open the circuit at h (see Fig. 35) while the wheel G and the tape are at rest, and prior to the time when either trailer, if it is in contact with its back

stop, can be separated therefrom by the advance of the tape. The opening of the circuit, therefore, always precedes the separation of the trailers from their contacts.

95. The collar *i* is quite long in the direction of the axis of the shaft *t*. The edge of the projection on the surface of the collar, which raises the bar *j*, is oblique to the axis of the shaft, while the other edge of the collar, which allows the bar *j* to drop down again and close the circuit, is straight or parallel to the axis, so that by adjusting the bar *j* bodily at right angles to the axis of the shaft, the period of engagement between a lug on the under side of the bar *j* and the projection on the collar may be varied, according as the lug on the under side of the bar *j* passes over a narrower or wider part of the projection on the collar. Furthermore, the collar may be turned around on the shaft and fastened in any position desired.

96. Since the magnets *C* and *D*, Fig. 35, are only energized when the circuit is closed at *h*, it will be noticed that the cable is connected directly to the ground at all times, except when the circuit is closed by the bar *j*. The circuit may be closed at the contact *h* at a time that is adjustable within limits during each revolution of the motor shaft, and then opened at *h* after an interval of time during which the tape wheel and trailers are absolutely at rest. Moreover this interval of time during which the tape wheel and trailers are at rest may be varied by means of a speed governor on the electric motor that drives the transmitter, and thus the relative lengths of the impulses and of the intervening spaces, during which the cable is directly grounded, and the speed of transmission may be varied to suit the requirements of working at any time or through any cable.

The tape may be stopped without stopping the motor, by moving the handle *b* to the right, thus forcing the lever *a* to the left and raising both trailers and the springs that press the paper against the wheel away from the wheel. The forked spring, on which the paper tape *K* is resting in

the figure, then lifts the tape above and free from the pins on the wheel *G*.

In connection with the electric motor, there is a speed regulator and indicator that is not shown in the figure. By means of the regulator, the speed may be adjusted as desired, and the divisions on a graduated dial will indicate the number of turns of the shaft per unit of time, and, hence, the average number of letters being sent per minute, or the rate of transmission.

EARTH CURRENTS.

97. The operation of submarine cables is interfered with by earth currents more than are land lines. This is due to the differences of potential at the two ends of a long cable, which cause a more or less steady flow of current, if means are not taken to prevent it. During electric or magnetic storms, temporary currents are induced in a long cable that are sometimes very troublesome, because the delicate instruments used on submarine cables are very readily affected by them. Such disturbances, however, are so uncertain both in intensity and time of occurrence that nothing is usually done to eliminate them. It is a well-known fact that the flow of a steady current can be prevented by the introduction of a condenser in the circuit; hence, steady earth currents are avoided in cables by the use of a condenser somewhere in the circuit between the ground and the cable. While a constant difference of potential between the two ends of the cable will charge such a condenser, there will be no steady flow of current through the cable or receiving instruments after the condenser is fully charged.

98. The electromotive force due to the earth is fairly constant and changes direction but seldom, while the direction of the electromotive force due to the transmitting battery is being constantly changed by the operation of the transmitting keys; hence, the earth potential alternately helps and opposes the battery potential. This may be obviated in two ways. A condenser may be inserted in the circuit

between the cable and the ground connection, and the potential of the battery increased until the potential due to the earth is insignificant compared with it. This will evidently make the component of the signaling currents due to the earth potential negligible in comparison with the component due to the transmitting battery. In order that the charging and discharging currents may not now be too large, they can easily be reduced in volume by decreasing the capacity of the condensers (as *C* in Figs. 37 and 38). Thus one way is to diminish the capacity of the condensers and to then increase the electromotive force of the battery until the disturbing effects of the earth currents are eliminated. This is the method adopted in practice.

99. When a condenser is inserted in series with the cable, the combined capacity will be less than that of either the condenser or the cable alone, because the capacity of condensers joined in series follows a law exactly similar to that for resistances joined in parallel. Hence, to give the same charging current, a higher voltage battery will be required with condensers than without. However, the potential of the batteries must not be increased too much, for there is danger of injuring the insulation of the cables. Fifty volts is about the highest electromotive force that can be safely used. Low internal resistance batteries, such as Fuller bichromate and storage batteries, having an electromotive force from 30 to 40 volts, are commonly used on submarine cables.

On transatlantic cables, the capacity of the condenser used for minimizing the disturbing effects of earth currents is about 50 microfarads.

100. The second way to eliminate earth currents is to determine at each end, by measurement or experimental trials, the intensity and direction of the potential between the ground and the cable conductor, due to the earth, and then to insert a battery of this potential in the ground wire so as to oppose it. An objection to this method is the fact that the battery potential will be constant, while the earth potential will vary more or less.

TERMINAL CONNECTIONS.

101. Submarine cables are worked both simplex and duplex. When sending, the cable is connected through a condenser, switches, ordinary cable key, and the battery to the ground. When receiving, the cable key and battery are switched out and the siphon recorder connected in their place. A condenser is connected in series with the receiving instrument because this arrangement increases the sharpness of the signals.

SIMPLEX CABLE CONNECTIONS.

102. Position of Switches for Transmitting.—When cables are worked simplex, they are often connected

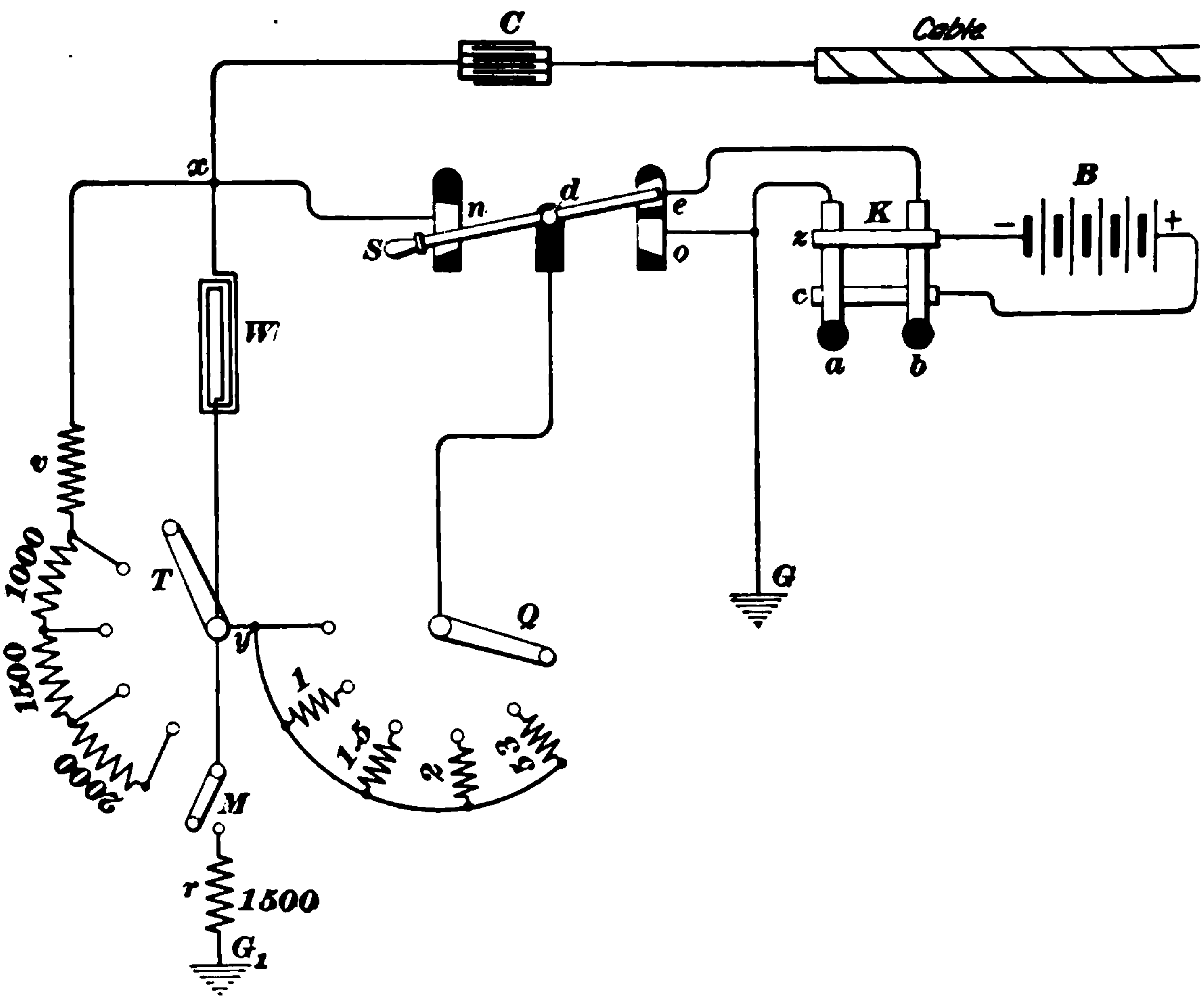


FIG. 37.

as shown in Fig. 37. Ordinarily, when transmitting, the switches will be placed in the positions shown. In this

position of the switches, the transmitting key K, battery B, and condenser C are connected directly in series between the cable and ground G; all the current is then utilized to charge the condenser and cable. The condenser C is used to eliminate earth currents and to increase the speed of signaling.

103. To Record Signals Sent From Home Office. If it is desirable to record the signals to see whether they are being properly transmitted or to preserve a record for future reference, the switches Q, T, and M are closed. The resistance r is usually as high as the resistance of the cable itself. When the two switches Q and M only are closed, there are two paths for the current that comes from the battery B; one is by way of d–Q–y–M to the ground G_1; the other by way of d–n–x–C and cable, to the ground at the distant station. Hence, if x and y have any difference of potential, some current will flow through W. This current may be increased by turning Q so as to increase the resistance between d and y, because this increases the difference of potential between x and y; or, it may be looked at in this way: The greater the resistance from d through Q to y, the greater will be the portion of the current flowing from d through n–x–W–y, and the smaller will be the portion flowing through the parallel path d–Q–y. The current through W may be decreased by closing the switch T. The more T is turned so as to increase the resistance from x to y, through x–v–T, which forms a shunt circuit around the coil W, the larger will be the portion of the current through W, and the smaller the portion through x–v–T–y. By adjusting the switches Q and T, the proper current may be obtained through W.

104. Position of Switches for Receiving.—When it is desirable to receive, the switch S is raised. This switch is so constructed that when this is done, the rear end of the lever touches the segment o before the front of the lever leaves the segment n. This is very necessary because it allows the cable to discharge to earth through n–d–o–G,

of through the coil W, as it would do if the switc[h] ver left n before touching o. When the handle of th[e]

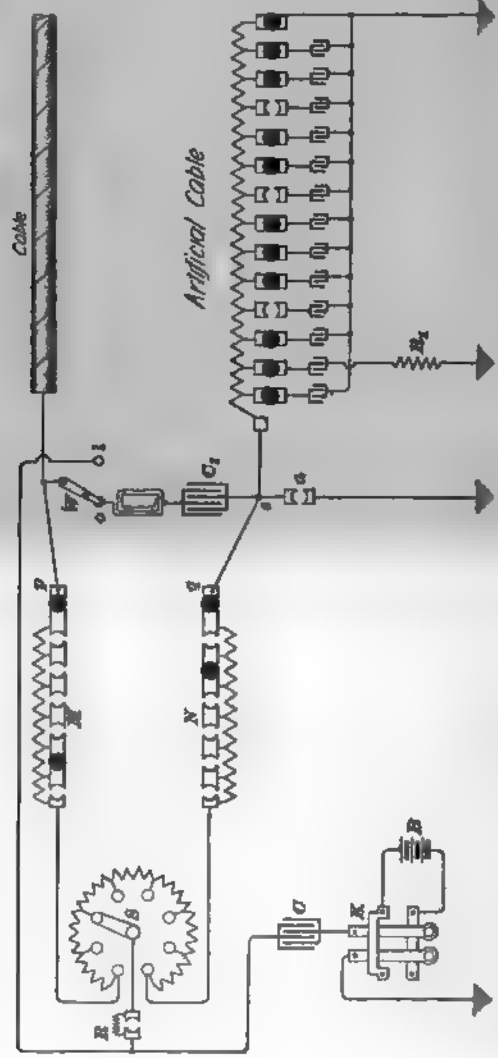


Fig. 38.

lever is up as high as it will go, contact between d and n is broken. The current from the cable then divides at x, part

passing through W and the rest through v and T to y, where the currents reunite and pass through Q–d–o to the ground G. When receiving, it is evidently immaterial whether M is closed or open.

CABLE DUPLEX.

105. When submarine cables are duplexed, the bridge method is generally used. One arrangement is shown in Fig. 38. M, N, and S are adjustable resistances forming two arms of the bridge, the cable and the artificial cable forming the other two arms. The artificial cable corresponds to the artificial line in the bridge duplex that has already been explained.

There are usually from 1,000 to 3,000 ohms in each of the boxes M and N, while S contains about forty $\frac{1}{4}$-ohm coils. C and C_1 are condensers of about 50 microfarads each. C is used to diminish the trouble due to earth currents and C_1 to make the signals sharper. R is a 10-ohm resistance coil that may or may not be connected in the transmitting circuit.

When one of the levers of the key K is depressed, one pole of the battery is connected to the condenser C, causing the latter to be charged. This will send charging currents which divide in such a manner through the arms of the bridge that there is no difference of potential between the points e and W; hence the receiving instrument connected between the condenser C_1 and the point o is not affected by the operation of the home key K.

106. The **Stearns artifical cable,** as the arrangement of the artificial cable here shown is called, consists of a large number of condensers and resistance coils put up in boxes. The coils and condensers are joined to terminals on the outside of the boxes, so that they may be connected together and to the ground in the way that will best resemble the real cable both in resistance and capacity. By connecting a condenser to the ground through a high resistance R_1, the discharge from that portion of the cable is retarded.

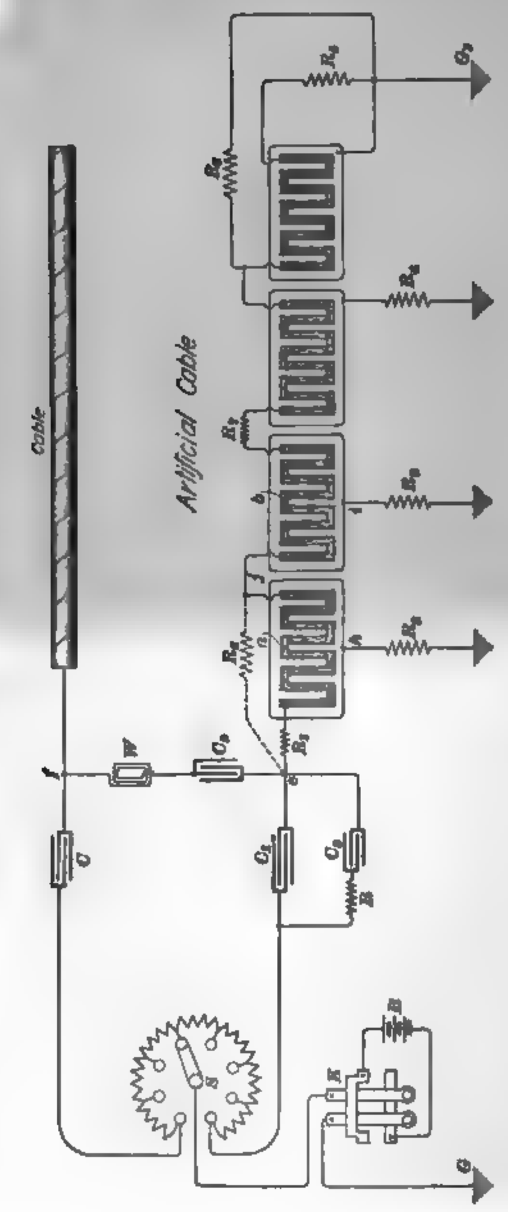


FIG. 39.

Hence the charge and discharge of the artificial cable may be accelerated or retarded to correspond to that of the real cable by connecting proper resistances between the ground and condensers at proper points in the artificial cable. Connecting resistances between the ground and condensers in the home end of the artificial cable will delay the discharge of the home end; and connecting resistances between the ground and condensers in other parts of the artificial cable will delay the discharge from those parts of the artificial cable. The more condensers that are connected to the artificial cable, the longer will it take to charge and discharge.

107. To Change From Duplex to Simplex.—When it is desired, as is often the case, to work the cable simplex, a plug is inserted at *a*, and the plugs at *p* and *q* are removed. When receiving, the switch W remains on contact button *o*, but when transmitting, it is shifted to the contact button *l*.

MUIRHEAD CABLE DUPLEX.

108. In the **Muirhead cable duplex,** shown in Fig. 39, the condensers C and C_1 are used in place of the resistances M and N shown in Fig. 38. A condenser C_2 is also connected in the bridge circuit *e f*. For the present suppose C_3 and R to be entirely disconnected. The condensers C and C_1 act in the same way as the resistances in a Wheatstone bridge. When connection is made at K with one pole or the other of the battery B, the condensers C and C_1, the cable, and the artificial cable are charged. A charge is given to the condenser at the distant station corresponding to C_2; but *if the charge of* C *is to the charge of* C_1 *as the charge of the cable is to the charge of the artificial cable, there will be no charge given to* C_2, because there is no difference of potential between the two points *e* and *f* to which the receiving circuit, containing W and C_2, is connected, and consequently the receiving instrument W is not affected.

The condensers and cable may evidently be charged in either direction by means of the key K.

109. As it is practically impossible to construct or build a number of large condensers, even out of exactly the same material, so that the rates of absorption of each will be the same, a supplementary condenser C_2 and an adjustable resistance R are often connected, as shown, in parallel with the condenser C_1. The resistance R is usually non-inductive, but there may also be included an inductive resistance so arranged that, by sliding a V-shaped iron bar in and out of the coil, its inductance may be varied. The condenser C_2, which is adjustable by steps of .01 microfarad, has usually a maximum capacity of 5 microfarads. The resistance R usually contains from 1,000 to 100,000 ohms. S is an adjustable rheostat of low resistance, containing about forty $\frac{1}{4}$-ohm coils and sometimes one or two 10-ohm coils. The receiving instrument at W is usually a siphon recorder. The arrangement of the artificial cable, condensers, and resistances shown in this figure is known as the **Muirhead double-block system.** Mr. Muirhead gave the following values as those required for balancing one of the Mackey-Bennett cables: C and C_1 120 microfarads, C_2 .15 microfarad, and R, 100,000 ohms.

110. Muirhead Artificial Cable.—The artificial cable shown in Fig. 39 is known as **Muirhead's artificial cable.** It consists of a very large number of sections, only four of which are shown in this figure. Each section consists of a thin sheet of insulating material, such as paraffined paper, on one side of which is placed a plain rectangular sheet of tin-foil, and on the other side a piece of tin-foil a of about the same outside dimensions, but cut as shown, so as to form a long zigzag conductor. These are piled up, but are separated from one another by more sheets of paraffined paper. The rectangular tin-foil sheets in one pile are connected together, and the zigzag sheets are connected in series, so as to form one long conductor. By means of the terminals on the outside of the box to which the two ends of

the zigzag conducting strips in each pile are connected, the zigzag strips in each pile as a whole may be joined to any other pile in any manner required. The strips are generally joined directly in series, but sometimes a resistance, as shown at R_7, is included. Enough of these zigzag strips of tin-foil are used to give a resistance equal to that of the real cable. The tin-foil being extremely thin and cut into quite narrow strips ($\frac{3}{8}$ to $\frac{5}{8}$ inch in width), has quite an appreciable resistance, and it is evident that sufficient resistance can be obtained by using enough sections. The sheets of tin-foil and insulating material can be pressed and packed very closely together; nevertheless, so many are required that the boxes containing them often measure several feet in each direction.

111. Terminals are also brought to the outside of the box from the rectangular sheets of tin-foil that are on the opposite sides of the insulation to the zigzag sheets. Some of these are joined together and to the ground, and some are connected through resistances, as at R_2, R_3, R_4, to the ground. R_1 is a resistance representing that of the land line from the cable station to the cable itself, and it does not usually amount to very much. At the end of the cable, the zigzag sheets are connected through the resistance R_5 to the ground G_1. In order to represent the small amount of leakage that there may be in the real cable, a high resistance R_8 may be connected between one of the zigzag sheets and the ground. In some cases, a resistance R_6 is connected between the point e and some point in the artificial cable, as j. This resistance, which is generally 80,000 ohms, or more, represents the leakage paths from the land lines and the first part of the cable. Thus the artificial cable may be made to resemble the real cable by having the same resistance, due to the zigzag sheets joined in series; the same capacity, due to the proximity of the zigzag sheets to the grounded rectangular sheets of tin-foil; and the same amount of leakage, due to the high resistances that are connected between the zigzag sheets of tin-foil and the ground.

It is especially necessary to make the home ends of the real and artificial cable resemble each other very closely; and for this reason the home end of the artificial cable is subdivided into smaller sections than the remaining portion in order to permit a closer adjustment of these resistances and capacities.

112. The resistances in an artificial cable may have about the following values: R_2, 175 ohms; R_3, 1,400 ohms; R_1, 40 ohms; R_5, 175 ohms; R_8 and R_6, 90,000 or more ohms, or is infinite, that is, disconnected. In some cases a resistance of about 500 ohms is placed in each arm between the condenser C and the point f, and between C_1 and e.

On one of the cables of the United States Cable Company, the following are the capacities and resistances used at one time at Nova Scotia: C, 41 microfarads; C_1, 40 microfarads; C_2, 41 microfarads; C_3, .28 microfarad; R_1, 29 ohms; R_5, 860 ohms; R_6, 90,000 ohms; R, R_2, R_3, R_4, and R_7, 0 ohms; R_8, infinite, that is, disconnected.

The condensers C and C_1 are 50 microfarads each, and C_2, 30 microfarads in the duplex arrangement used in connection with the Coney Island cable of the Commercial Cable Company between New York and Nova Scotia. This cable has a total resistance of 13,700 ohms, a capacity of 231.4 microfarads at 75° F., and a length of 880.6 knots. The condensers C and C_1 upon the same company's No. 3 Atlantic cable between Nova Scotia and Waterville, Ireland, are each 80 microfarads capacity. This cable has a total resistance of 4,895 ohms, a capacity of 914 microfarads at 75° F., and a length of 2,164 knots.

113. Balancing Cable.—In effecting a balance of such a system as shown in Fig. 39, the artificial cable is first of all made equal in resistance, capacity, and leakage to the real cable; the condensers C, C_1, and C_3 are then inserted and their capacities and the resistance of S adjusted to give a close balance. Then a slight increase is made in the capacity of C_3—say by 1 microfarad—and by trials the right amount of resistance required in the various rheostats

is ascertained. If the artificial cables discharge too rapidly, more resistance must be inserted between the ground and the condenser plates. A sharp signal would indicate that the near end of the artificial cable was not properly adjusted; a faint signal, that the far end was not properly adjusted. When the home receiving instrument is not affected by the operation of the home key, the adjustment is correct. The artificial cable seldom needs adjustment more than twice a year and the bridge arrangement by means of the resistance S and condenser C_3, seldom oftener than once a day.

DUPLEX FOR A MIXED OVERHEAD AND CABLE LINE.

114. The arrangement shown in Fig. 40 is that used in some countries for automatic duplex systems over a circuit consisting of both land lines and underground, or short submarine, cables. PC represents a transmitting key or device,

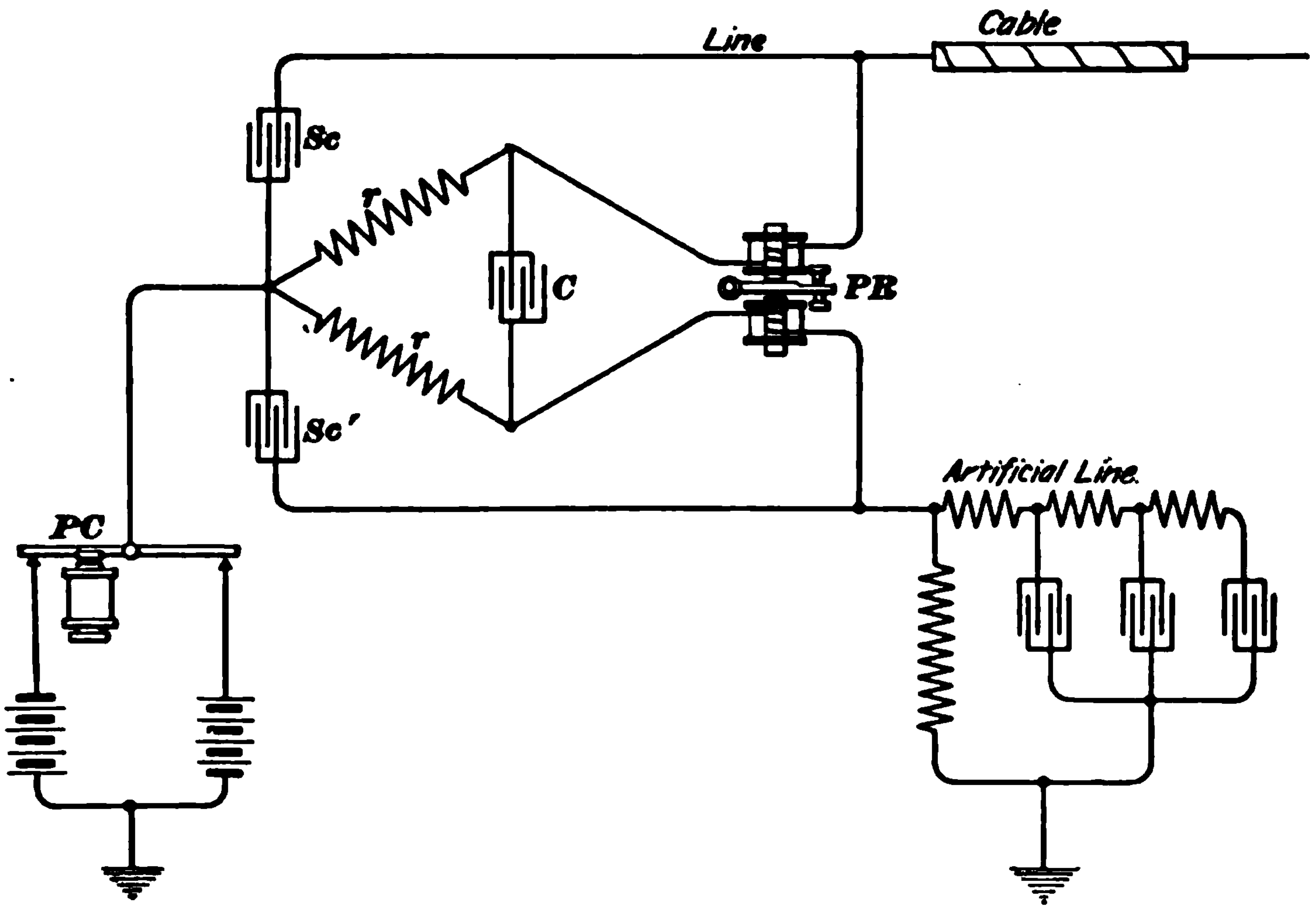


FIG. 40.

often the Wheatstone automatic transmitter; PR a differentially wound receiving device, often the polar relay of

the Wheatstone automatic recorder; Sc and Sc' so-called "signaling condensers"; and C another condenser connected across the polar relay and the ends of the adjustable resistances r, r. This is really a differential polar duplex. When the transmitter opens the circuit, the discharge from the condenser C tends to neutralize the extra current due to the inductance of the relay coils. The condensers Sc and Sc' shunt the discharging current from the cable and artificial line past the coils of the relay PR. Preece and Sivewright state that these signaling condensers have a disadvantageous effect upon the received signals, but that this may be compensated by using a condenser of larger capacity at C. They further state that the attainable speed on two circuits was doubled by adding the signaling condenser compensation illustrated in this figure. The speed on one circuit was increased from an average of 60 to 120 words per minute by using the connections shown in this figure with the Wheatstone automatic transmitters and receivers.

HIGH-SPEED TELEGRAPHY.

115. In telegraphy, as in nearly all other industries, there are two ways of working—by hand and by machine. Naturally the hand method comes first. Even now, probably 90 per cent. of the telegraph business of the world is done by hand. In America and England, it is done by hand and sound; in all other countries, by hand and sight, although Belgium is just beginning to use the sounder. France, Germany, Italy, Austria, Spain, Russia, and, in fact, the rest of the world, use the Morse key and a receiving instrument that records the dots and dashes in ink upon a paper tape. There are, however, a number of through circuits operated by the Hughes system. Transmission is by keyboard, and the message is received printed on a tape, similar to the type-printing system of Phelps, which is used to a small extent in this country.

England may be said to be the only country using machinery to any considerable extent for the operation of its telegraphs, having adopted the Wheatstone automatic telegraph system, which is an English invention.

WHEATSTONE AUTOMATIC SYSTEM.

116. The **Wheatstone automatic telegraphic system** is capable of transmitting and recording in ink signals at a rate of 500 or 600 words per minute, the speed below 600 depending on the electrical properties of the line. Over 225 words per minute can be transmitted between New York and Philadelphia, 190 words between New York and Chicago, and 110 words between Chicago and San Francisco. Between Calcutta and Bombay, which are 1,300 miles apart, 130 words per minute are transmitted without the use of repeaters. Where the line is long, repeaters are used. Between North Sidney and New York, over land lines, the Wheatstone is worked duplex, having a speed of about 100 words per minute. The Wheatstone system is extensively used in Great Britain, where it has given better results than in the United States, since in the latter country it is used on comparatively few circuits.

This system consists of a perforator that punches holes in a paper tape to represent dots and dashes; a transmitter, through which the paper tape is fed and by means of which electrical impulses are sent into the lines; and a receiver that records in ink the electrical impulses as dots and dashes upon a paper tape that is drawn through the receiver.

PERFORATOR.

117. The **perforator,** or punching apparatus, is shown in Fig. 41. It has three keys and five punches so arranged that pressing key *A* makes perforations in the paper tape *D* corresponding to a dot, pressing down *C*

makes perforations corresponding to a dash, and pressing down B makes one perforation corresponding to a space and is also necessary for advancing the paper tape. The paper tape passes behind a punching plate G containing 5 holes into which the ends of the punches enter in the act of punching corresponding holes in the paper tape. When the key A is depressed, three holes corresponding to m, n, and o are simultaneously punched in the paper, as shown at A_1; when the key is released, the wheel F revolves and teeth on its surface engage the center line of holes made in the paper and so advance the paper a distance equal to the proper distance between two center holes. When the key B

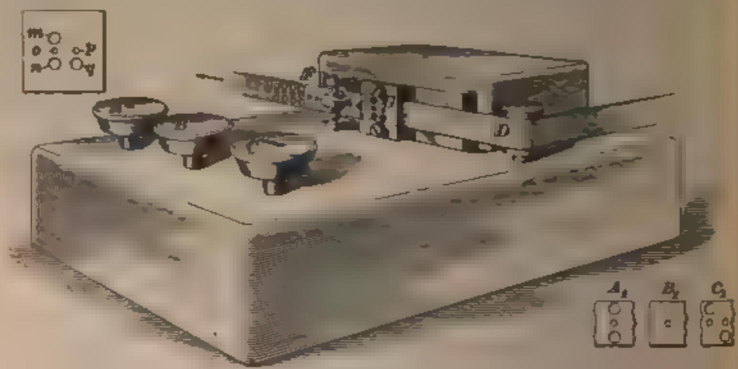


FIG. 41

is depressed, one center hole is made by the punch at o in the paper, as shown at B_1; and the releasing of the key again advances the paper the same distance as before. When the key C is depressed, four holes corresponding to m, o, p, and q are simultaneously punched in the paper, as shown at C_1, and the releasing of the key advances the paper double the distance that is accomplished by the release of either of the other keys A or B. The double advance in this case is evidently necessary; for, otherwise, if A or B were depressed after C, some of the punches would enter holes already made in the paper by the depression of C.

The perforations A_1 made by the left-hand key A, when passing through the transmitter, cause a dot; the perforation B_1 made by the center key B causes a space, and the perforations C_1 made by the right-hand key C cause a dash to be printed on the tape at the receiver.

118. The student will understand this better when the transmitter and receiver have been described. The operator manipulates these three keys A, B, and C by pounding, or striking, them with rubber-tipped pieces of wood, one held in each hand. As this is laborious, they are sometimes arranged so that a key, which is very easily depressed, will operate the punches by pneumatic pressure. The pneumatic pressure is sufficient to punch from 4 to 8 tapes simultaneously at the rate of 40 words per minute. Although about 45 words per minute can be punched by pounding or pneumatic pressure by an expert operator, 40 words is considered a very good average speed.

NOTE.—Mr. J. Willmot (see "Electricity," March 28, 1900) has recently made some improvements in the steel punches used in the Wheatstone perforator, and has also improved the Wheatstone transmitter.

TRANSMITTER.

119. The object of the transmitter is to transmit the dot-and-dash alphabet by means of positive and negative currents. These currents are transmitted alternately in opposite directions; the arrangement of the transmitter and receiver is such that the current, whether positive or negative, continues to flow and produce a mark whose length varies according to the time that elapses before the current is reversed—such reversal producing an interval or space, whose length continues to increase until the current is again reversed in direction. Since alternate currents flowing in opposite directions produce the to-and-fro motions of the ink wheel in the receiver, lines of various lengths, that is, dots or dashes, may be printed. Hence it is necessary to send a current in the opposite direction through the line

and receiver before a mark or a space that has once been started can be terminated. The contact device in the transmitter exists in several slightly different forms, the result of improvements made from time to time. In this Course the latest arrangements will be shown.

120. Inside of a case is placed suitable clockwork and gearing for operating the transmitting mechanism, which is supported on the side of the case. This transmitting mechanism is shown in Fig. 42. The wheel *l*, which is driven by the clockwork, has teeth upon its surface suitably

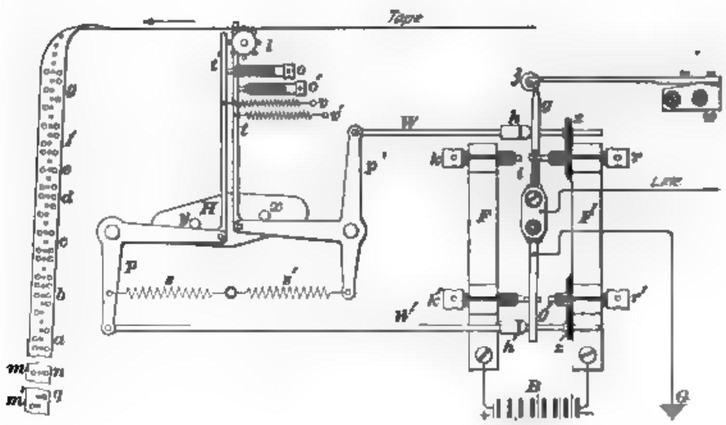


FIG. 42.

spaced to enter the holes along the center line of the previously punched transmitting tape and to draw it along at a steady desirable rate This rate can be varied by an ingenious speed regulator to suit the conditions of the line circuit. The greater the *K R* of the line, the slower must be the speed of transmission.

The rocking beam *H*, as its name implies, has a rocking motion given to it by a shaft to which it is rigidly fastened at the center. This shaft is operated by the same clockwork that rotates the wheel *l*, and, hence, its rate of oscillation corresponds with the rate of rotation of the wheel *l* whether the transmitter is running fast or slowly. On the rocking beam

are two pins x and y against which the levers p and p' are pressed by the springs s and s'. Hence the rods t and t' move up and down as the two pins x and y on the beam H move up and down. Now t and t' are so adjusted by the screws o and o', against which they are held by the springs v and v', that the horizontal distance between them is exactly equal to the distance between the centers of the two holes o and p in Fig. 41. Moreover the distance between the two rods at right angles to the plane of the figure is exactly equal to the distance between the centers of the holes m and n in Fig. 41. Hence the rod t is directly below whatever holes may have been punched on one side of the center line of holes and the rod t' is directly below whatever holes may have been punched on the other side of the center line of holes. The springs s and s' always tend to force the rods t and t' upwards and to push the rods W and W' to the right.

121. The apparatus at the right constitutes a pole changer. The lever gg' is pivoted at the center and has attached to, but entirely insulated from, it a contact piece i, to which the line wire is connected. The metal piece F, to which is attached the positive pole of the battery B, has two contact screws k and k'; and the metal piece F', to which is attached the negative pole of the same battery, has the two contact screws r and r'. The insulated piece i moves between the two contact screws k and r, and the lower end of the lever gg' moves between the two contact screws k' and r'. W and W' are two rods having fastened to them the collars h and h', respectively, which are called *collets*. The rods pass freely through the lever gg' without touching it, and have bearings in the pieces z and z', which are insulated from the metal piece F'. The rod W pushes the lever to the position shown in the figure, and W' pushes it over so that i rests against the screw k and g' against the screw r'. Neither rod, when moving to the left, can move the lever. The wheel j, termed the *jockey wheel*, is fastened on the end of a flat spring that is adjustable at w. It is used to help move the lever gg' sharply to one side or

the other, to prevent the lever from remaining in an intermediate position, and to hold it against whichever side it may have been pushed by the rods W and W'.

122. When the pin x moves upwards, the rod t will move upwards; and if there is a hole directly above it, the rod t will enter the hole and continue to move upwards as far as the pin x will allow it. On the other hand, if there is no hole directly above it, the upper end will come against the paper tape, and although the pin x continues to move upwards to the end of its stroke, the rod t can go no farther. Similarly the rod t' will move upwards as far as the pin y will allow, provided there is a hole in the tape directly above it; otherwise it is arrested in its upward movement by the tape. If the tape contained a series of holes, like those at A_1 in Fig. 41, representing a series of dots, there would be a hole directly above both t and t' every time these rods came up and this would transmit, as we shall see, a succession of negative, or marking, currents the proper length for dots, and a succession of positive currents, producing the break or space between the dots. The motion of the wheel l and the rocking beam H is such that the tape is advanced exactly the distance between two center holes while the rod t or t' moves once down and up. Hence these rods will pass through every hole that is punched on either side of the center line of holes.

123. For instance, assume that the rod t projects through the hole m. When the rod t is drawn down by the downward movement of the pin x, the paper will be moved forwards the proper distance to allow the rod t', as it moves up, to enter the hole n. At the start, when the rod t moved up through the hole m in the tape, the rod W would push the collet h, and with it the lever g, over to the right so far that the jockey wheel j would slip down and press on the left side of the lever g and so hold i against the contact r and g' against the contact k', causing the negative pole of the battery B to be connected to the line and the positive pole to the ground G. This state will continue, in

spite of the fact that *W* moves to the left, until the rod *t'* can enter a hole in the tape. Then the rod *W* will push *g'* over until the jockey wheel *j* slips down on the right of *g*, and so holds *g'* against *r'* and *i* against *k*. This will reverse the battery *B*, connecting the positive pole to the line and the negative pole to the ground.

Suppose the rod *t* is in the hole *m'* and the negative pole of the battery connected to the line. As the rod *t* moves down and the pin *y* moves up, the paper will advance, but *t'* can move up but little, if at all, because it comes up against the paper opposite the hole *m'* where there is no hole. Consequently the lever *g g'* is not disturbed and the negative pole of the battery *B* remains connected to the line. When *y* moves down and *x* moves up, the rod *t* comes against the paper opposite the hole *q*, where there is no hole, and again the lever *g g'* is not disturbed. When *y* moves up again, however, the hole *q* will be in line with *t'*; hence the rod *W* will push *g'* to the right and, by aid of the jockey wheel *j*, will reverse the battery, causing the positive pole to be now joined to the line. The time between reversals, in this case, when a dash is made, is three times (two dots and one space) as long as it was when a dot was made. A space is evidently started by a hole on the lower or right-hand side of the tape, and the space will continue until a hole on the upper or left-hand side of the tape comes opposite the rod *t*, thereby pushing *W* and *g* to the right and so starting a dot or a dash. Thus dots and dashes are transmitted by currents in one direction and spaces by currents in the opposite direction; a reversal of current is necessary in any case to terminate a signal, be it a dot, dash, or space.

124. Improvements Made by Willmot.—An improvement of the transmitter just described has been made recently by Mr. J. Willmot, of England. He has substituted a permanent magnet and a soft-iron tongue in place of the jockey wheel, and has made quite a number of improvements in the details of construction that reduce the

wear and tear to which high-speed apparatus is especially subject. The arrangement of the improved transmitter is shown in Fig. 43. The lever g, which is made of soft iron, vibrates between the poles N and S of a permanent magnet. The soft-iron piece g will, of course, be attracted by both the north and south pole of the permanent magnet and it will move rapidly toward and remain firmly against

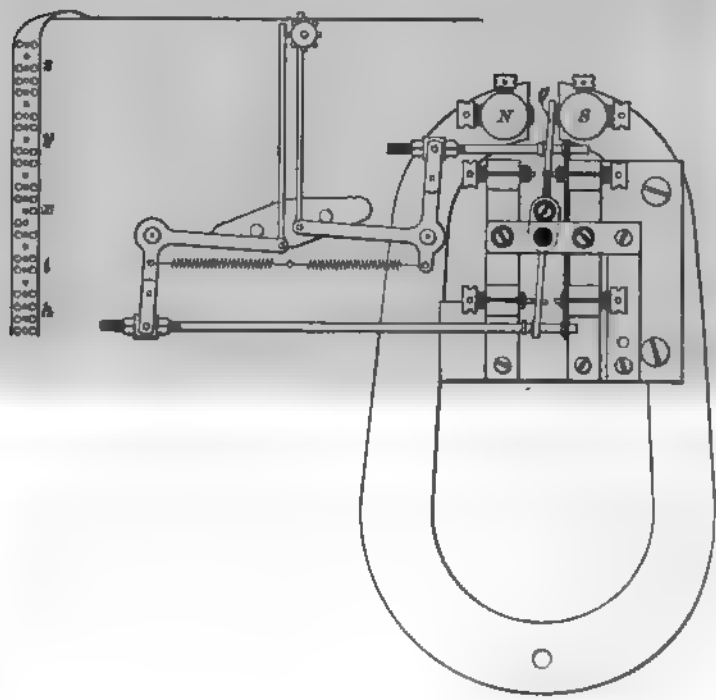


FIG. 43.

whichever pole it happens to be nearest. The use of magnetic attraction in place of the jockey wheel entirely removes the downward pressure of the jockey spring, and greatly increases the holding-over force operating upon the lever, thereby causing a better contact between the contact points. The force necessary to drive the instrument when fitted with the magnetic arrangement is considerably less

than with the jockey roller, due to the fact that the downward pressure on the pivots is entirely removed. Furthermore, the laws of magnetism hold, and no sooner does the lever commence to move from the pole of the permanent magnet to which it is nearest than the attractive force of that pole from which it is receding diminishes inversely as the square of the distance, while the attractive force of the pole that it is approaching increases inversely as the square of the distance—a condition most favorable to the object in view.

RECEIVER.

125. The **Wheatstone receiver,** or **ink recorder,** as it is also called, consists of clockwork operated by a weight and a very sensitive polarized relay. It is shown in Fig. 44. Inside the case is placed the polarized relay and also the clockwork that revolves the wheel *c*, the ink disk *i*, and the ink-supply wheel *b*. The paper tape on which the ink records are made by the ink disk *i* is drawn by the roller *c* from the base of the instrument, where it is coiled away. The speed of the clockwork, and hence the speed of the tape, can be regulated by means of the handle *f* to suit recording at any speed from about 25 to 600 words per minute. The ink wheel *b*, which dips into a covered ink well *g*, has a V-shaped groove around its periphery. This is shown better in Fig. 45. The edge of the revolving ink disk *i* enters this hollow in the periphery of the wheel *b*, but it never actually touches the wheel. Thus there is no friction between the revolving disk and wheel. During the revolution of the ink wheel *b*, capillary attraction keeps the hollow full of ink, and a constant and uniform quantity is supplied to the ink disk *i*. The clockwork is started and stopped by means of the handle *a* and wound up by the handle *Q* in Fig. 44.

126. The **Wheatstone polarized relay** that moves the ink disk *i* against the paper tape as it is drawn along is shown in Fig. 45. The relay consists of a permanent

magnet P across whose ends is a vertical shaft h to which is rigidly fastened the soft-iron armatures n and s and the arms j and k. The soft-iron armatures are permanently polarized by the permanent magnet P.

Two vertical electromagnets m and m' have polar extensions opposite each other and between which the soft-iron armatures s and n can move. These two soft-iron armatures

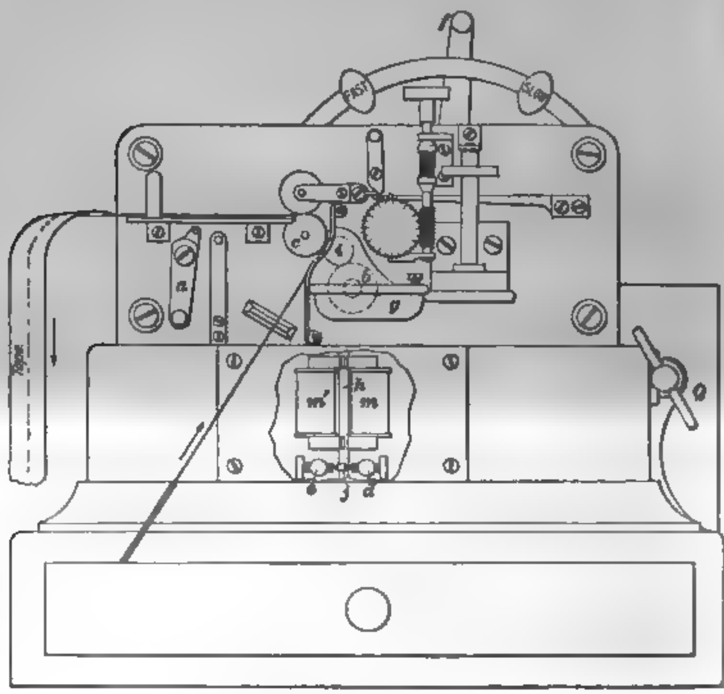


FIG. 44.

are rigidly fastened to the shaft h; but their motion, which is exceedingly small (about one-fourth degree), is limited and adjusted by the stop-screws d and e. When the magnets are energized by a current, the polar extensions opposite each other are oppositely magnetized; hence each armature s and n is repelled by one and attracted by the opposite polar extension, and the polarities of the four polar extensions are always such that they all tend to move both armatures

toward the same side. When the current is reversed, the polarities of the four polar extensions are reversed and both armatures move toward the other side.

The shaft *l*, which is pivoted at the end *o* and caused to revolve by the wheel *o*, rests lightly in a cavity at *r* in the arm *k*. When the armatures move away from the reader, the arm *k* moves the ink disk *i* toward the moving tape, on which it makes a dot or dash, depending on the length of time that the marking current lasts. When the current is reversed, the armatures move toward, the reader and the ink disk away

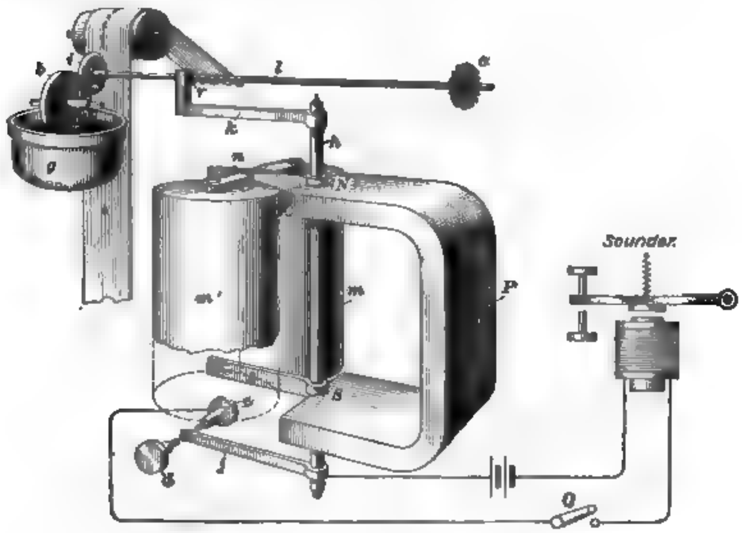


FIG. 45.

from the tape, making a space that lasts until the current is again reversed. Hence a series of instantaneous, alternately positive and negative currents passing through the electromagnet will cause a to-and-fro motion of the marking disk *i*, a current in one direction pressing the marking disk against the paper, where it will remain until withdrawn by a current in the opposite direction.

127. The motion of the armature is limited by the screws *d* and *e*, which are shown in both figures; one may be

used as a contact screw at which is opened and closed the circuit of a local sounder that is used to attract the attention of the operator, and also for reading messages when the line is being operated manually by a key.

In the base of the transmitter is placed a triple switch, by means of which the automatic transmitting apparatus may be cut out and the battery connected to a hand transmitting key. This switch is worked by the lever used for starting and stopping the clockwork. By this arrangement, messages may be transmitted by hand On the transmitting key there are also switches enabling the operator to cut the key and batteries out of the circuit when he is receiving messages by means of a local sounder controlled by the polarized relay of the automatic receiver.

128. Resistance and Inductance of Wheatstone Relay.—The relay used in the Wheatstone receiver is generally wound differentially, so that the system may be worked duplex. To give the two coils exactly opposite magnetic effects for duplex working, the two wires are wound together as one upon the spool; the resistance of each coil is made equal to 100 ohms in the British service. The inductance of a 200-ohm Wheatstone receiver, with the two coils of the relay connected in series, is about 3.46 henrys; with the two coils in parallel, about .875 henry. When the two coils are differentially connected and the current flows in the proper direction to create an equal but opposing magnetization, the inductance is about .187 henry.

129. Non-Inductive Resistances and Condensers in Wheatstone System.—In practice it is found that when the Wheatstone receiver is connected directly in the line and is operated by the Wheatstone transmitter, the speed obtainable over most lines can be increased by the use of condensers properly arranged. The arrangement of condensers and resistances in actual use in England is indicated in Fig. 46. Common values of the resistance and capacity are about 8,000 ohms and 10 to 20 microfarads,

respectively, which will vary according to the line. The non-inductive resistance is often larger than the impedance of the receiver.

This arrangement reduces the retardation due to the self-induction of the receiver relay. It increases the total resistance of the circuit considerably without increasing the inductance; hence the time constant of the receiving apparatus is considerably reduced. Moreover, the condenser connected in this manner also helps to make the current start and stop more abruptly, because the moment the circuit is opened at the transmitter, the extra current due to the electromotive force of self-induction of the relay is opposed or neutralized by the current discharged from the condenser. In the Wheatstone system, this arrangement has proved to be better than connecting the condenser around the coils of the relay itself.

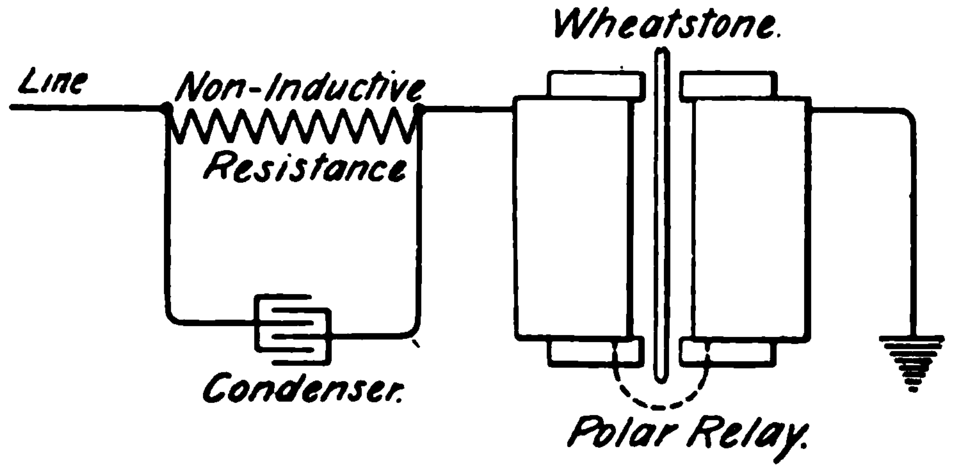


FIG. 46.

130. Non-Inductive Resistance Around Relay Contacts.—A small but important addition, which has been made in England, to all local apparatus, i. e., apparatus worked by relays, has been the general introduction of a non-inductive shunt, or *spark coil*, as it is called, of high resistance connected across the terminals of the relay. This has resulted in the suppression of the spark at the relay contacts and a consequent greater certainty of action. This improvement has been quite generally applied to all relays and not alone to the Wheatstone relay.

131. Limiting Number of Words per Minute.—The present perfection of the Wheatstone system is much superior to that obtained with the original instruments. This improvement is due to Mr. Preece, who has gradually

the speed from 100 or 200 to 600 words per minute.

... atstone system has been in commercial operation in En... nd for so long a period that the speed expected on any given line is accurately known, and may be represented closely by an equation of the form

$$W = \frac{a}{KR}, \qquad (1.)$$

where K denotes the total distributed capacity of the line, R the tota resistance, W the number of words per minute, and a a constant. The constant a depends on the kind of line used, a... d differs for iron and copper wire ... d for cables. The value. of the constant a determined ... y a series of experiments extending over a long ... od are as follows

10×10^6 for aerial line of ir... ire.

12×10^6 fo... line of copper wire.

15×10^6 ... arine cable with condenser at one end

18×10^6 ... marine cable with condensers at both ends.

A copp... al line having a KR equal to about 30,000 will redu... e Wheatstone speed to about 400 words per minute; when a line exceeds this it is customary to insert an automatic repeater, by which the speed is maintained over longer distances. Speeds of 400 words per minute are regularly maintained in England in commercial working, while the limit of the commercial working in the United States is considerably lower, about 200 words per minute.

WHEATSTONE DUPLEX.

132. The arrangement of the Wheatstone apparatus when worked as a polar duplex with dynamos as a source of current is about as shown in Fig. 47. The polar relay is wound differentially and the line and artificial-line circuits run through separate coils of the differential galvanometer DG. The two coils of this galvanometer have the same resistance and the same number of turns and are wound in such a direction that equal currents through the

two coils from the home station will not deflect the needle. The duplex system is balanced by means of this galvanometer. An expert is able to tell from the action of the galvanometer needle whether the pulses received from the

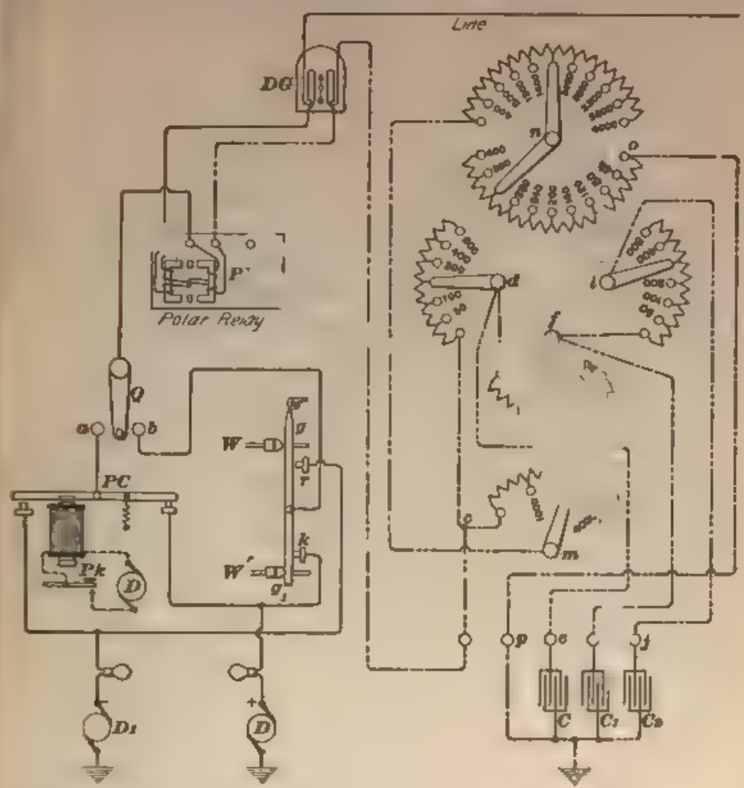


FIG. 47

distant station differ in strength or duration, whether the distant batteries are short-circuited or open, whether the home instruments, resistance, and condensers are properly adjusted, while grounds, crosses, and breaks on the line each produce effects readily recognized.

133. When the switch *Q* rests on *a*, messages may be sent manually by means of the key *Pk* and the pole

changer PC; when the switch rests on b, the automatic transmitter may be used. The latter instrument is somewhat altered when used with dynamos so that it resembles the ordinary walking-beam pole changer, $g g_1$ representing the beam or armature lever, and r and k the positive and negative contact stops, respectively. The lever $g g_1$ is joined to the point b.

For a high-speed duplex system, the line must be much more carefully balanced than for a manual duplex system. For this reason three retarding coils are required: one $c d e$ in series with the condenser C; a larger resistance $c d f h$ in series with the condenser C_1; and a still larger resistance $c d f i j$ in series with C_2. The condenser C must have the largest and C_2 the smallest capacity; the rheostat consists of the coils in the circuit c–m–n–o–p.

134. Balancing.—The system is balanced by asking the distant operator to run his transmitter while the home artificial line is adjusted in the usual manner. If balanced properly, the galvanometer should give no deflection when the switch Q is placed on a and the key Pk is operated.

To further eliminate the disturbing effects of the static line charges, the home transmitter should be run and the condensers and the retarding coils adjusted until the incoming signals made by the receiver are clear and distinct.

WHEATSTONE REPEATER.

135. Repeaters known in Great Britain as "fast-speed" repeaters are used in connection with the Wheatstone apparatus when the latter must be worked over long circuits. The value of the repeaters for speed purposes may be illustrated by the fact that direct working between London and Aberdeen (560 miles) would not be possible at a higher speed than 40 words per minute, whereas with repeaters at Leeds and Edinburgh, the practical working speed is increased to 350 words. These repeaters in their

present efficient form have been introduced within the last 25 years and are marvelous examples of ingenuity. The present form of this apparatus, for use on cable circuits, comprises 41 instruments of 26 different forms; it is arranged to work bridge duplex on the cable side and differential duplex on the land side of the circuit.

DELANY SYNCHRONOUS MULTIPLEX TELEGRAPH SYSTEM.

136. The system devised by P. B. Delany, of South Orange, New Jersey, is based on two main principles: *first*, that of synchronism, or the simultaneous motion of similar pieces of apparatus at two different places; *second*, that of distributing to several telegraph operators the use of a wire for very short equal periods of time, so that practically each operator has the line to himself during these periods.

137. As Delany's system is so entirely different from the duplex and quadruplex systems, it is proposed for clearer definition to give to the modes of working his system names based on the Greek word *hodos* (a way). Thus a two-way mode of working, or a mode by which two messages are practically sent at the same time, will be *diode* working; three-way, *triode;* four-way, *tetrode;* five-way, *penthode;* and six-way, *hexode*.

Duplex and quadruplex are such well-rooted and explicit terms defining particular modes of working by compensation, that their application to different modes of working based on a different idea may lead to confusion, while new and distinct terms will confine the attention to a new and distinct system.

138. In Fig. 48 (*x*), *A* and *B* are two separate offices connected together by a line wire *L*. If the arms *a* and *b*, which are in electrical connection with the line wire *L* at *A* and *B*, respectively, rotate simultaneously around the circles *1–2–3–4* at each station in the direction of the arrows,

making contact upon the segments as they pass, then, when *a* touches *A–1*, *b* will touch *B–1*; when *a* touches *A–2*, *b* will touch *B–2*; and similarly for *3* and *4*. If *1*, *2*, *3*, and *4* at each office are each in connection with a set of similar telegraphic apparatus, the four sets at one office will be in

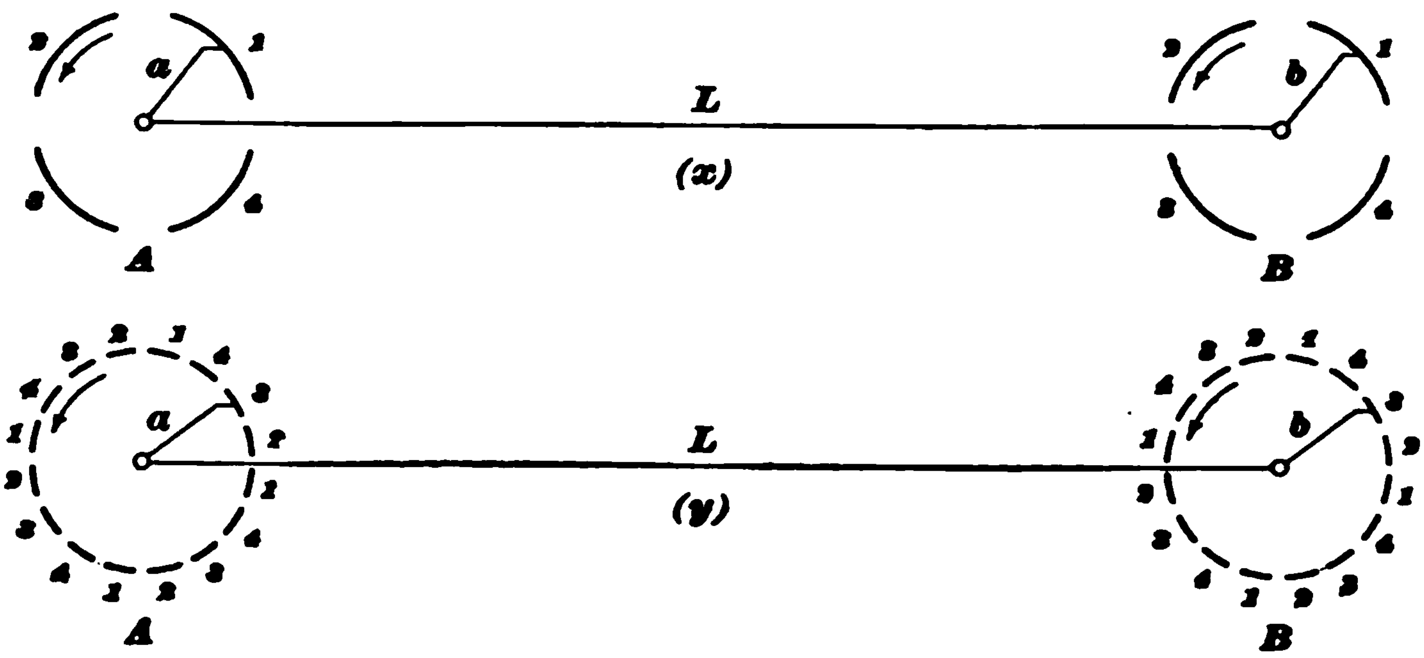


FIG. 48.

direct communication with the four sets at the other office as the arms *a* and *b* touch their corresponding segments. Thus, for each rotation of the arms, the instruments connected to *A–1* and *B–1* will be in direct communication with each other once; and so on with those connected to *A–2* and *B–2*, etc.

139. If each segment be divided into four segments as shown in Fig. 48 (*y*), and every fourth one of these smaller segments is connected with one of the four instruments instead of one large segment being connected with only one of them, as in (*x*), then, during one complete rotation, each arm will place corresponding instruments, one at each end, in communication with one another 4 times. Or, if each circle be divided into 40 segments and each of these 40 into four segments, then corresponding instruments will be in communication with each other 40 times during each complete rotation of the arms *a* and *b*. In Delany's apparatus there are 84 segments in the whole circle, and these are grouped according to the number of ways of working. Hexode working requires one grouping, triode another, diode another, and so on.

140. To Maintain Synchronism. — Two tuning forks pitched to absolutely the same note and set in vibration by currents like an electric trembling bell, will move in synchronism, but the synchronism cannot be maintained. The deposition of dirt, dust, or moisture, changes of temperature, and variation of current produce changes that affect the rate of motion.

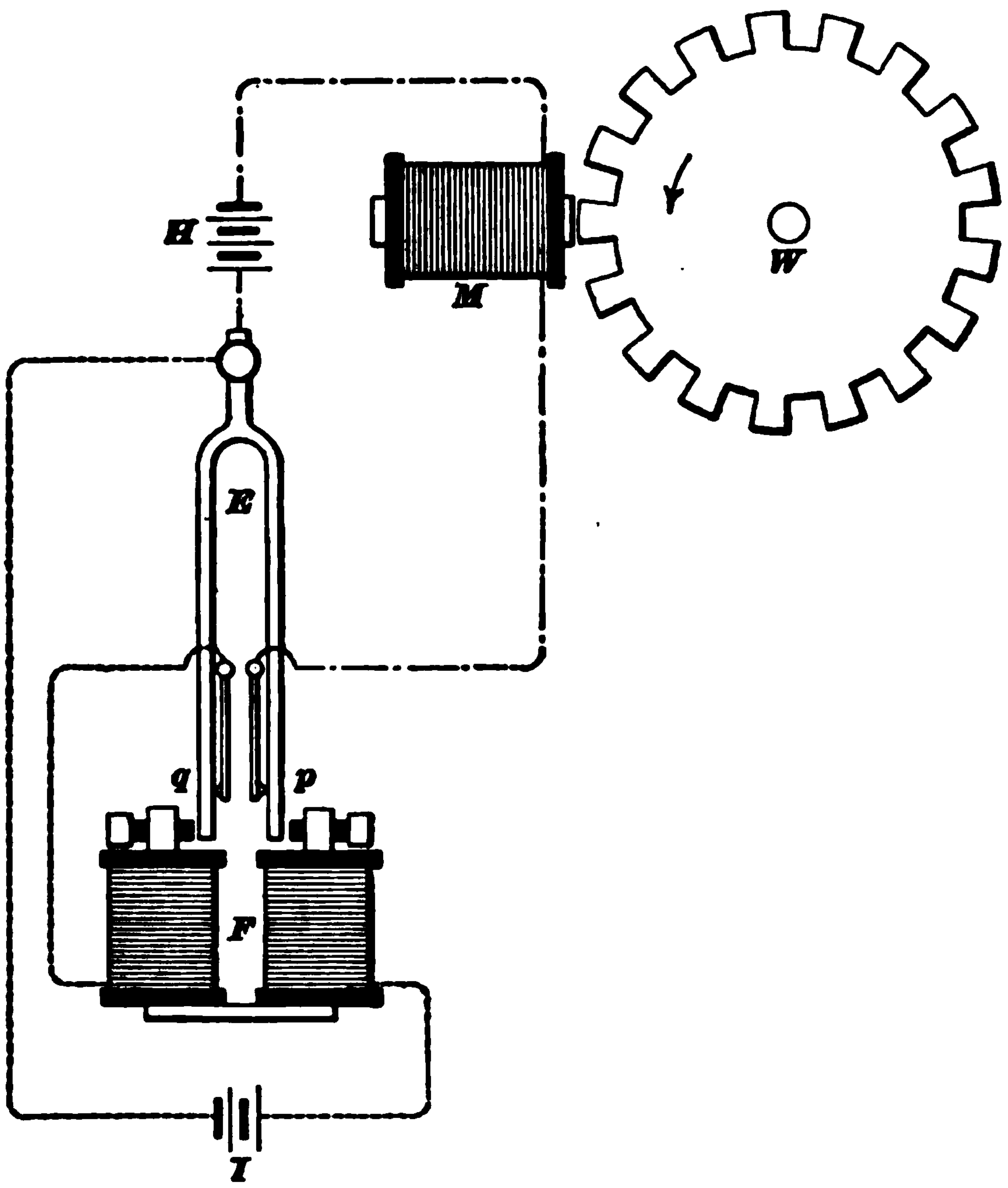


FIG. 49.

Paul la Cour, of Copenhagen, invented an ingenious way to maintain synchronism. In Fig. 49, *E* is a tuning fork vibrating between the poles of the magnet *F*. There are two contact points *p*, *q*. At *p* is completed a circuit containing the battery *H* and an electromagnet *M*. The other contact *q* completes the circuit containing the battery *I* and the electromagnet *F*. Every time the tuning fork touches the contact point *p* a current is sent through the electromagnet *M* which, therefore, is magnetized once for every movement to

and fro of the fork. In front of the magnet *M* is a wheel *W* having iron teeth, and every time the magnet *M* is excited,

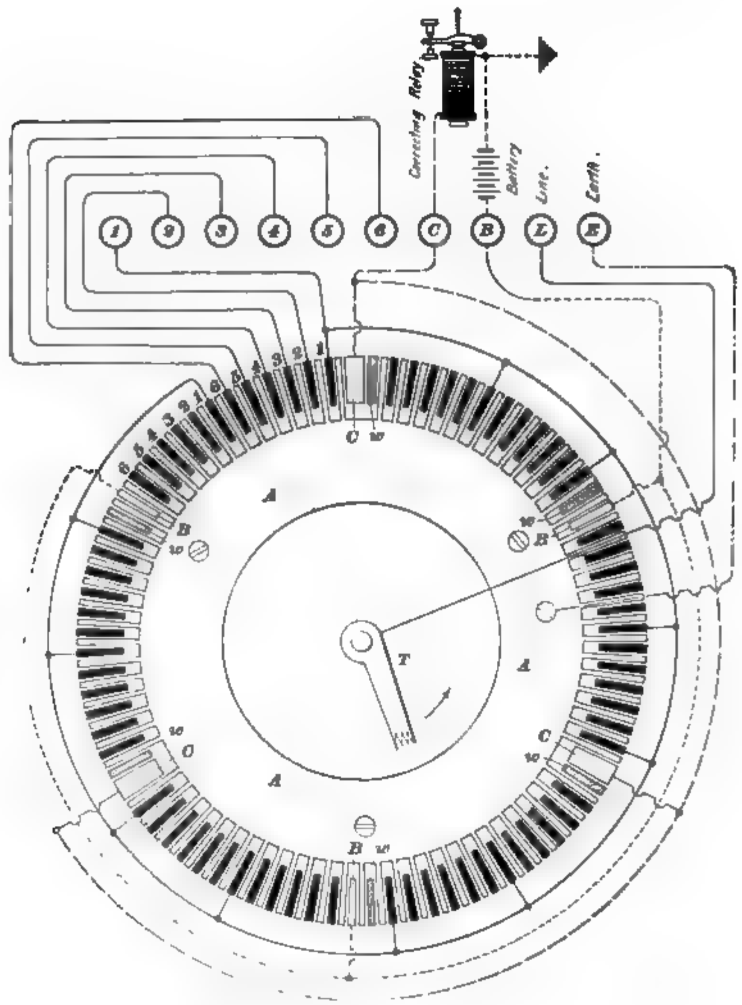
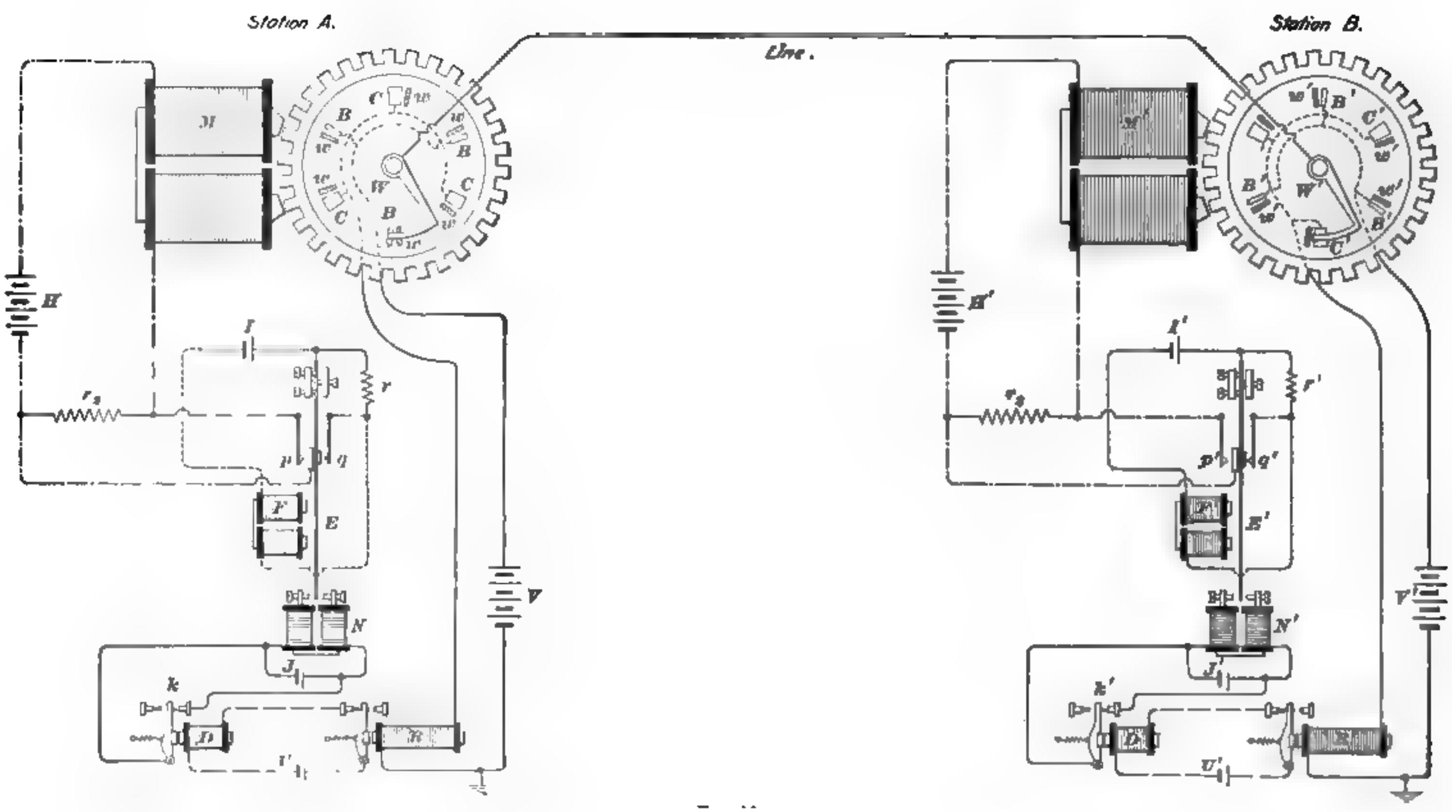


FIG. 50.

attraction is momentarily exerted on the nearest tooth. If the tooth is approaching the pole, it is urged forwards, and if it is moving away from the pole, it is retarded; hence, the wheel

can be propelled with wonderful uniformity and with considerable force. The electromagnet *F* is similarly excited, and it keeps the fork in constant vibration. The wheels must be started by giving them a turn by hand, as they will not start otherwise. Delany uses this *phonic wheel*, as it is called, in connection with a *distributor*, but he has adopted a reed instead of a tuning fork.

141. The **distributor,** as arranged for hexode working, is shown in Fig. 50. The circle is divided into 6 groups, each group having 12 platinum-faced brass segments insulated from one another, and being separated from the next group by what are called the two *correcting segments*, one (shaded and marked *w*) called a "dead" segment, and the other (clear and marked *B* or *C*) called a "live" segment. The dead segments *w* are entirely insulated, the live segments *B* are connected through the binding post *B* to the battery, and the live segments *C* to the correcting relay. All the segments are not only insulated but are also separated from one another by the spokes of the brass ring *A*, which is connected with the earth. Each group of 12 segments is further subdivided into 2 subgroups of 6 segments each, in which the corresponding segments are connected, so that *1* and *1*, *2* and *2*, *3* and *3*, and so on are electrically joined together. Not only so, but they are connected to every corresponding number in the other groups around the circle. In Fig. 50, the segments in only 2 of the subgroups are numbered, but the remaining 10 subgroups must be understood as being numbered in the same way. The 12 segments numbered *1* are electrically connected through the binding post *1* to the telegraph instrument numbered *1*; the 12 segments numbered *2* are connected through the binding post *2* to the instrument numbered *2*; and so on. The first, third, and fifth live segments, that is, the *C* segments, are connected together and to a so-called correcting relay; they are intended to receive currents from the distant station. The second, fourth, and sixth live segments, that is, the *B* segments, are also connected together and to a battery, and so



Station A.
Station B.
Line.

can send currents to the distant station. The "dead" segments are so arranged that one is fixed before each receiving "live" segment *C*, and one after each sending "live" segment *B*.

142. Correcting Segments on Lines Having Large Capacity.—The correcting segments are connected in the manner just described for lines whose electrostatic capacity is small, and where the retarding effect on the current is, consequently, slight; but when the capacity is considerable, the segments that are called "dead" are brought into use. A correcting battery is then connected to the "dead" segments immediately in front of the broad "live" *C* segments, and a receiving correcting relay is connected to the "dead" segments immediately following the narrower "live" *B* segments. This arrangement gives a space of one segment to allow for retardation of the current when the capacity of the line exceeds 3 microfarads. When, however, the capacity is within that amount, this space is not required; indeed, it would be disadvantageous, because there is then a very slight loss of time in the transmission of the signal. The receiving correcting segment is, therefore, extended in such a manner as to meet the trailer, and so receive the correction almost as soon as it is sent. It is not really necessary that the segment should be made broad, but only that it should be moved in the direction indicated—it is only made broad to fill up the space.

143. The arm or trailer *T* presses lightly upon the surface, and moves continuously around the circle, coming successively in contact with every segment. It moves in the opposite direction to that of the hands of a watch, and is electrically connected to the line wire *L*. In every rotation it makes 84 electrical contacts, 72 of which are for telegraphing, while the others are for maintaining synchronism.

The function of the trailer is to place the line wire successively in connection with the segments in the different groups. The currents of electricity that flow through the

line wire are dependent on the operations performed on the telegraphic apparatus, and are broken up into short rapid pulsations or impulses by the momentary contacts made by the trailer. The uniform rotation of the trailer is produced by La Cour's wheel, shown in Fig. 49.

144. Fig. 51 shows the La Cour wheel in connection with Delany's actuating, correcting, and synchronizing devices. The iron-toothed wheel *W* is placed before the poles of the electromagnet *M*, which is magnetized periodically and regularly by currents from the battery *H* sent at each vibration of the reed *E* against *p*. It propels with great uniformity the toothed wheel, to whose axle the trailer is attached. Momentum carries the wheel until the next tooth approaches, when the next impulse is given. As the impulses are due to the vibration of the reed, the motion of the wheel follows these vibrations, which are maintained by the electromagnet *F*, which is excited by the battery *I* every time contact is made at *q*.

145. Non-inductive resistances r **and** r_1 **are placed** as shunts around each of the contacts q and p to prevent sparking. A resistance of 100 ohms in series with a condenser of $\frac{1}{2}$ microfarad capacity may also be used as a shunt around the magnet *M*, instead of the resistance r_1 as shown in this figure. Furthermore, it is sometimes advantageous to connect a condenser in a shunt circuit around the relay *R*.

146. The end of the iron reed *E* vibrates between the extended pole pieces of the electromagnet *N* and, consequently, vibrates in a magnetic field. This magnet is excited by the battery *J* whenever contact is broken at *k*, and this contact at *k* is broken whenever the current from battery *U* ceases to flow in *D*. The interruption of the current from *U* through *D* depends on the action of the relay *R*, which is excited by currents sent from the distant station coming through the live correcting segments *B'* of the "distributor" there, and received through the live

correcting segments C at the home station. When the armature of the relay R is attracted, it breaks the local current flowing through D and opens a short circuit around the battery J at k. When the magnet N is excited by the opening of the short circuit at k, the magnetic field in which the iron reed vibrates tends to retard the rate of vibration by attraction, so that if the reed vibrates too frequently its rate is checked. The normal rate of vibration may be adjusted by a sliding weight, or in various other ways not shown in the figure.

147. The manner in which each set of apparatus is connected is shown by Fig. 52. The segments of the "distributor" at each station are indicated, and the trailers are shown in contact with corresponding segments that direct the current to the No. 1 telegraph set. The relay R, by its form, is rendered sluggish, so that the sharp rapid currents collected by the trailer are practically made continuous in their action on the armature of the relay. The currents flowing through the line wire are short, sharp, rapid impulses, or waves, of electricity, and to convert these waves into telegraphic symbols, such as Morse characters, some such method is needed to render them practically continuous for the duration of a dot or a dash.

148. The **relay** has a condenser C connected around it and a permanent horseshoe magnet O fixed below the coils. The cores are thus polarized more or less. The result is that the self-induction of the coils, assisted by the charge and discharge of the condenser, retards the demagnetization of the core, so that the effect of the rapid succession of short currents is made continuous upon the armature of the relay, and the marks are made as though they were produced by continuous currents. Dots and dashes are thus recorded without breaks. The relay R operates a repeating sounder or relay RS, which, in turn, operates the sounder S. This arrangement is introduced because in the ordinary method of completing the local circuit, the contacts are not firm enough.

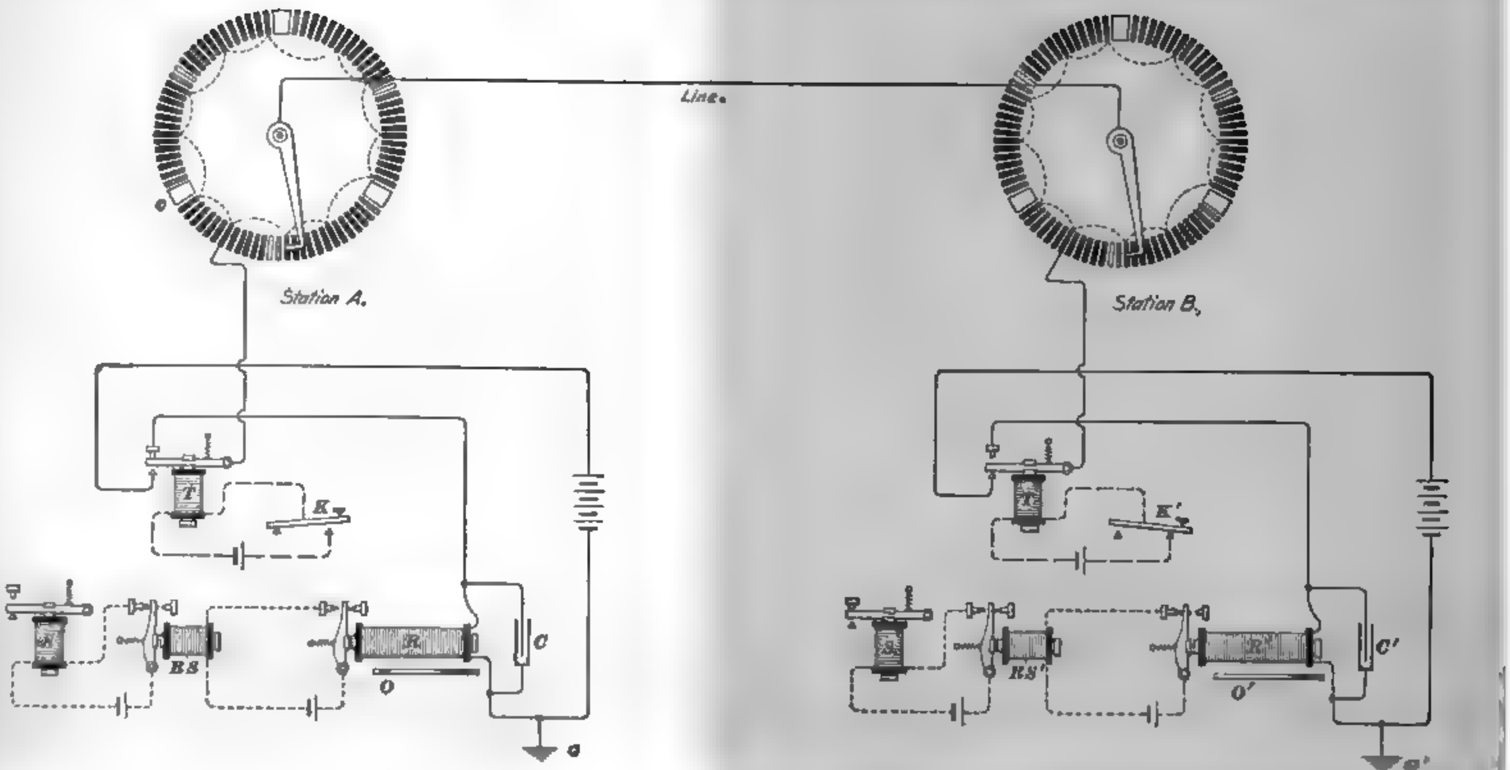


FIG. 55.

149. Line Grounded Between Each Current Impulse.—It has been mentioned that each segment is separated by an earth contact—a spoke of the brass rim. This is done to favor the rapid discharge of the static charge to earth between each electrical impulse or current. The apparatus being ready, six pairs of operators are placed in communication and each pair has virtually a circuit to itself.

150. In Fig. 51 only the correcting "live" and "dead" segments are shown. Of the "live" segments, those in connection with the battery are of the usual dimensions, while those in connection with the correcting relay and the reed apparatus are broad. This is to admit of corrections being made *before* the working segments are effected. Want of synchronism is thus prevented. When the trailer at station A is on the narrow live segment B, the trailer at station B is on or near the broad live segment C'. If the wheels are in perfect synchronism, the trailer at station B is on the dead segment W when the trailer at station A is on the sending live segment B, and *vice versa*, hence no current flows. But when the wheel at station B is in the least degree in advance of that at station A, then the trailer at station B is on the receiving live segments C', while the trailer at station A is on the sending live segments B'. Hence current flows and excites the relay R'; the electromagnet D' releases its armature, thus opening the shunt around N'; hence N' is magnetized and the vibration of the reed E' is retarded. Perfect synchronism is again obtained and the correcting current ceases to flow. Six correcting currents can be sent at each revolution, three in one direction and three in the other. Thus a deviation of a thousandth of an inch can be speedily rectified.

151. The method of Mr. Delany is perfectly automatic in its action, practical and successful. The "distributor" rotates nearly 3 times in 1 second, hence 252 contacts are made each second in hexode working. The distance to which the system can be worked hexode is limited; for,

owing to the retarding effect of static induction, the number of currents that can be sent per second is limited by the static capacity of the line. Now as the static capacity of the line has the effect of retarding the speed of a signal, it follows that the limit of working is dependent on the magnitude of the static capacity, for if the signaling current be late, it will enter the wrong segments, and confusion of signals will result.

The retarding effect of static capacity can be met by making each group of a greater number of segments, or by making the segments of greater breadth; but this has the effect of reducing the number of ways of working. Either plan will reduce the hexode to tetrode or triode working.

152. Working in One Direction Only.—So far, it should be understood, the system has been described as one for working in either direction (not simultaneously as in duplex, but alternately), as in ordinary simplex working. If, however, it is used for working in one direction only, distance has not the same effect upon it. If the static capacity so reduces the speed of the signaling current that, while it leaves segments *1* at station *A*, it enters segments *2* at station *B*, then it is possible to still work five ways *in one direction*, for every segment at one end will be advanced one segment, or the distance of one segment. For this mode of working two wires are necessary, one for sending and the other for receiving; but it has this advantage, that two wires can be converted into ten circuits. Segment *6* is rendered useless in consequence of the current arriving at station *B* when the trailer is on the correcting segments.

Working hexode in either direction is feasible between London and Brighton, but tetrode is the limit to Bristol and Manchester. In one direction, however, to Bristol and Manchester even six circuits have been operated, so that with two wires 12 circuits might be worked, 6 in each direction. It is more difficult to adjust the system for working in both directions than for one direction only.

153. Advantages of This System.—The Delany system, somewhat modified and improved, is now being successfully used in England. Its great advantage over other systems is that it does not disturb the general mode of working. The sounder, relay, and key system is retained. All initial delay due to punching, as in automatic systems, is avoided. The skill of able operators is fully utilized and each operator has practically an independent circuit. When there is a rush of traffic in one direction, the system can be worked all in one direction, and not only half of it as in the quadruplex.

TELEGRAPHY.

(PART 6.)

CHEMICAL TELEGRAPH SYSTEMS.

154. Higher speed than the Wheatstone system will give at the receiving end of a line may be obtained by electrolysis. It is at least 10 times quicker than the fastest electromagnet that is found in the latest Wheatstone receiver. Receiving instruments all require a certain amount of energy to operate them, and, in addition, most of them have inertia in the moving parts. The Wheatstone receiver, which has come into successful operation, may be taken as representative of a type of receiver possessing inertia in the moving parts. As a type of instrument having no inertia in the recording mechanism may be mentioned the various forms of chemical receivers acting by electrolysis.

155. A simple method of obtaining records of transmitted currents is to place chemically prepared tape upon a smooth metal surface, which serves as one electrode, and to draw over it a steel needle that acts as the other electrode. If a direct current is used, no record appears when the current is in one direction, but it does appear when the current is reversed. If two needle electrodes are placed side by side upon the tape, a record will appear at one needle for a direct current, and at the other for the reversed current.

With the exception of the Wheatstone transmitter, which is entirely too slow for chemical telegraphy, all mechanical transmitters used or proposed have heretofore consisted of

a revolving wheel over which the perforated tape was drawn. This wheel was connected to the transmitting battery. On top of the tape pressed a scraping finger, which was connected to the line. When a hole in the paper came between the line and the wheel, an impulse was transmitted. Contacts made in this way were rather imperfect, and frequently missed altogether, on account of the collection of dirt and dust on the face of the wheel.

156. Tailing.—Suppose that the electromotive force has acted long enough for the current at the receiver to reach its steady value, and then that the circuit is suddenly broken at the transmitter. Some time will elapse before the current in the receiver is reduced to zero. The manner in which the break is made must be considered. A slow break when there is an arc, or a spark, is different from a rapid one. The whole line has been charged to the limit of the electromotive force used and must become sufficiently discharged before the next wave can be received. This produces the effect commonly known as **tailing**, which means that a signal becomes so drawn out at the receiver that it interferes with the following signal.

Mr. Delany uses impulses of equal duration and indicates the directions of these impulses, whether positive or negative, by a chemical receiver. If impulses, or waves, of equal duration are used, evidently more of them may be received in a given time than of any other combination of waves—for the shortest wave that will operate the receiver may be used. With this plan the effect of tailing is reduced.

157. Reversed Currents of Equal Duration.—A system using current waves of different duration, as sent out by a Wheatstone transmitter, is not as simple as one that uses current waves of equal duration, because in very high-speed systems a long line receives a larger charge when the current flows longer in one direction than in the reverse direction. Hence, a shorter current following a longer current in the reverse direction leaves the line partially charged. Consequently a signal will depend on the length

of preceding signals. The difficulties become apparent only when it is attempted to send waves of unequal duration at a very rapid rate, which is desirable in machine telegraphy. The current requires time to become established at the receiving end of the line after the electromotive force is introduced at the sending end. There is evidently a practical limit to the shortness of the time that the electromotive force must remain applied, which is determined by the smallest current that the receiver is capable of recording. If the potential between the terminals of the receiver is increased, the time required to make a given record is correspondingly reduced.

158. Chemical receivers possess many advantages, perhaps chief among them being the fact that a large part of the energy received is brought to bear directly upon making the record. Another feature is the simplicity of the essential mechanism involved, as no intermediate steps are used after the impulse is received from the line before the record is made. These qualities alone imply rapidity, and the chemical receiver is one of the most rapid known.

DELANY CHEMICAL TELEGRAPH SYSTEM.

159. Most of the above obstacles to high-speed telegraphy by chemical recording apparatus and automatic transmitters have been overcome by P. B. Delany's system for machine telegraphy. The three principal features of machine telegraphy are the perforator, transmitter, and receiver. The following description of this system has been taken from a paper that Mr. Delany presented to the Franklin Institute in 1895.

THE PERFORATOR.

160. The perforating machine, as shown in Fig. 53 (x), comprises three keys—one dot, one dash, and one space key; two electromagnets C and B, for forcing the punches

the tape; and a step-by-step tape-feeding device *m*, *n* ontrolled by an electromagnet *A*.

...peration is as follows: The ribbon is perforated in two ... s, the holes in the top line representing dots; those in the lower line, dashes. The letters are made of combi- ...ons of dots and dashes, preferably according to the ...ntal code. The lower contacts of the three keys ...nnected to one pole of the battery *LB*. The dot-key ... is connected to the punch magnet *C*, the dash lever to punch magnet *B*, and the space lever to space magnet *A*.

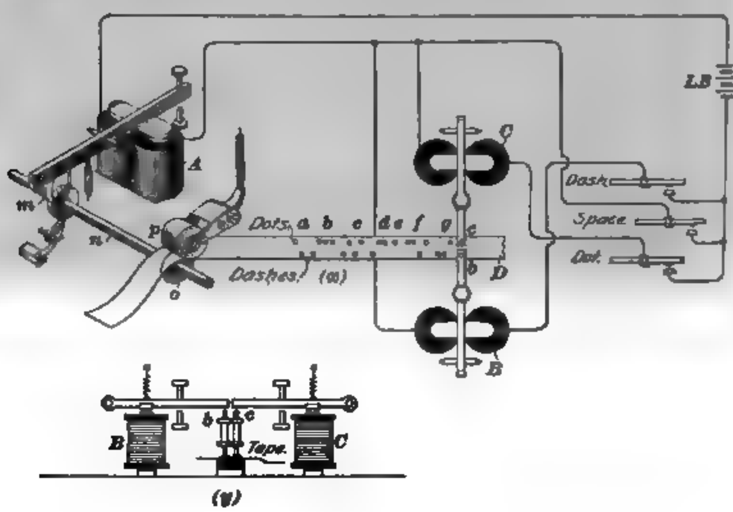


FIG. 53.

Obviously, but one key is pressed down at a time. The spacing magnet is in series with the dot and the dash magnets. To punch the letter *A*, the dot key is pressed down, magnet *C* forces its punch through the paper, and, at the same time, the lever of the space magnet is drawn downwards, and pawl *m* takes a new tooth in the ratchet wheel on shaft *n*. When the key is released and the circuit broken, the punch is raised out of the die and the strip is drawn forwards a definite length by the saw-tooth wheel *o* and pressure wheel *p*. Then the dash key is operated in the

same way, after which the space key is touched, which provides a space between the letter punched and the one that is to follow. Thus, the space key is pressed down once after each letter, and three times after each word.

Perforating is no more laborious than working an ordinary Morse key, and the speed, with a little practice, will be fully up to the average of Morse transmission.

A side view of the punch magnets, their levers, and punches is shown in Fig. 53 (*y*).

THE TRANSMITTER.

161. The **transmitter,** as shown in Fig. 54, consists of a paper-pulling device, represented by roller *R*, and the two pairs of wire brushes pressing toward each other above and below the tape. The top brushes are electrically one, and are connected to the line. The two bottom brushes are insulated from each other, one being connected to the

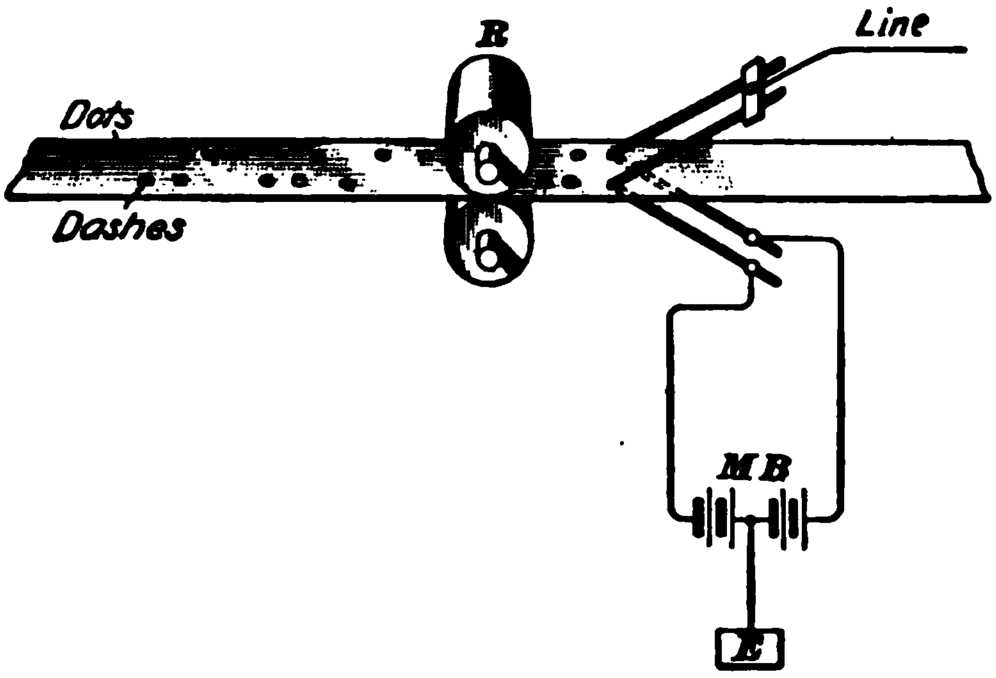


FIG. 54.

positive, the other to the negative pole of the main transmitting battery *M B*. This battery is connected to earth at its middle.

The paper tape usually separates the brushes. However, when a hole in the top line is drawn between the brushes, a positive impulse, representing a dot, is sent into the line,

and when a hole in the lower line is drawn between the other brushes, a negative current, representing a dash, is sent into the line. In this manner all the dots and dashes on the tape are transmitted.

162. The brushes are made up of six wires each, so that six contact points come together at each perforation, rendering failure impossible and insuring perfect uniformity in the quality of the impulses. The ends of the brushes are kept bright and clean by the edges of the holes, and a pressure may be put upon them that will insure electrical contact with the tape moving 30 feet per second, or at the rate of 8,000 words per minute, or over 2,500 impulses per second.

In this form of transmitter, there are no movable or adjustable parts, no circuit wheels to get dirty, no loose or lubricated contacts. An electric motor is used to pull the perforated tape.

163. It will be seen that as no dashes are sent, but only dots, some of which, owing to their position on the tape, *represent* dashes, the impulses are of uniform duration, and the line is not more heavily charged at one time than another; and consequently the discharge is also uniform, and the signals on the receiving tape are correspondingly regular.

THE CHEMICAL RECEIVER.

164. The **receiver** is shown in Fig. 55. It comprises a wheel over which the chemically moistened tape is drawn under three thin iron wires that press lightly upon its top. The two outside wires are electrically one, and are connected to earth E. The middle wire is insulated from the others and is connected to the line.

When the brushes of the transmitter drop into a hole in the dot line, a positive current is sent, and a dot is marked in the track of the middle wire of the receiver. When the transmitter brushes drop into a hole in the lower, or dash, line of perforations, a negative current is sent, and a dot is

marked in duplicate on the receiving tape, one in the track of each of the outside wires. This impulse is but a dot in duration; but as it is meant to represent a dash, it must have something to distinguish it from the dot signal; therefore, the current is forked or divided on the receiving tape, so that all dashes are in the form of double parallel dots, while the dots proper are single, and occupy the center line on the

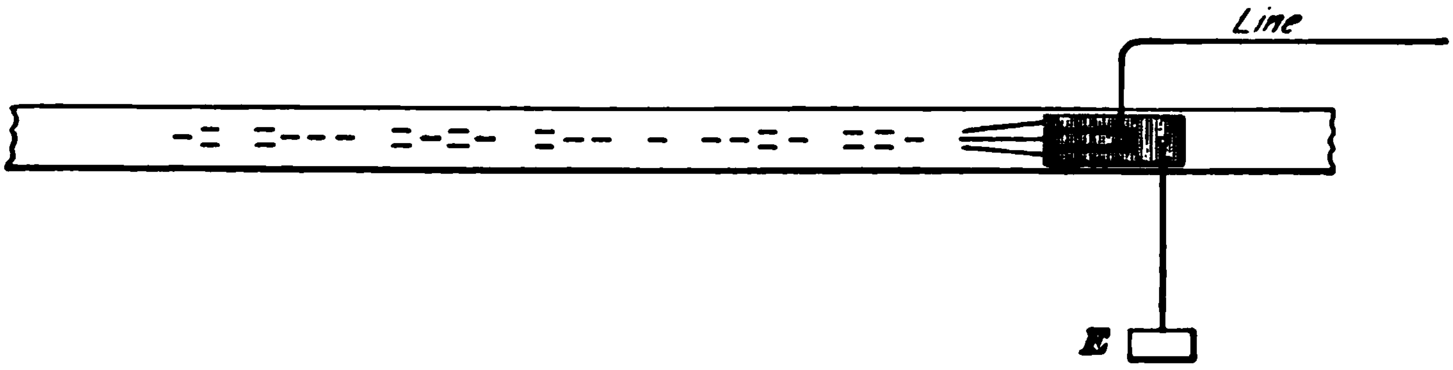


FIG. 55.

tape. It will be understood that the chemically moistened tape forms the circuit between the center wire and the outer wires of the receiver, or between the line and earth; and that all positive currents come over the line and mark in the track of the middle wire, while negative currents come from the earth and mark in the track of the two outside wires, forming double dots, which are recognized as dashes.

165. In this way, no matter how bad the "tailing" may be, it is impossible to mistake a dot for a dash, or to connect them together erroneously; neither is it necessary to have definition between successive dots or dashes. The length of the composite, single or double mark, determines at once the number of distinctive marks intended.

In this system of perfectly straight marks in distinctly different lines, translation is much easier than in submarine-cable signaling where a change in the direction and amplitude of a very irregular curve distinguishes dots from dashes.

166. The specimens of record *A* and *B* seen in Fig. 56 illustrate this most important feature. *B* shows the word "telegraphy" with clearly defined individuality of each dot and dash. *A* shows the same word without any definition

ut, notwithstanding, the word to a practiced eye
sin in this form as the other. It is safe to say
with few weeks' practice, the transcriber would not
for nition in signals.

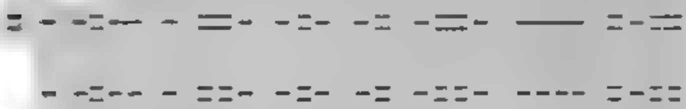


FIG. 56.

It will be clear, then, that a length of line or rate of peed that would render signals by the ordinary dot-and-dash method utterly illegible would be perfectly practicable with this method.

167. Specimen Transmitting and Receiving Tape.—In Fig. 57 is shown a portion of a message as it was actually punched in the tape for the transmitter, and the same message as actually recorded by the receiving instrument on the chemically prepared tape. These are reproductions of the sending and receiving tapes of a portion of

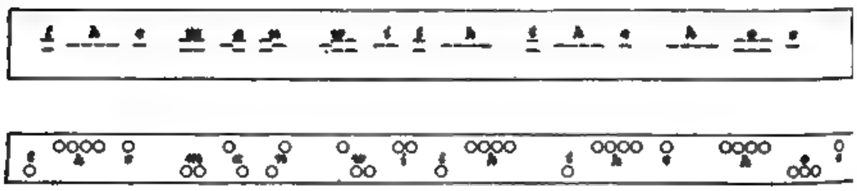


FIG. 57.

a message actually transmitted at the rate of 2,000 words per minute. The Continental code was used. The relative lengths and appearance of the two tapes have been reproduced as accurately as possible.

168. Speed of Transmission.—A perforator will prepare messages as fast as a Morse operator will transmit by hand. The machine transmitter will send, between New York and Philadelphia, over a common iron wire, at least 1,000 words a minute, or as much as can be sent over 50 wires by hand, simplex. If quadruplex is used, 15 wires

will be required to compete with this machine system on one wire. With a copper wire of 500 pounds to the mile, the machine system will carry 2,000 words per minute, or as much as can be carried by 30 wires worked quadruplex.

169. Trial Results.—On October 13, 1895, a trial was made over a wire from Philadelphia to Harrisburg and return, 216 miles, principally of No. 11 copper wire, 130 pounds per mile, and about 25 miles of ordinary iron wire. The speed reached was 940 words per minute, perfect record. The weather on that occasion was very stormy and the leakage of current very great. So far as resistance is concerned, this circuit was about twice as long as a line of 850 pounds per mile of copper would be from New York to Chicago, but the electrostatic capacity was very much less. The electromotive force used was 120 volts, or about one-half the pressure used for quadruplex (Morse) working.

170. Solutions for Chemical Receiving Tape.—The solution for saturating the paper tapes used in chemical telegraph receivers should be one that is easily decomposed; it should contain some so-called deliquescent chemical, that is, a chemical that does not dry out, but rather absorbs moisture from the air; the record made should be permanent; and the resistance of the moistened paper should not be too high. The resistance may be reduced by putting a little sulphuric acid in the solution; not enough, however, to act upon and corrode the marking styles. A good chemically sensitized paper will have a resistance of about 275 ohms between the marking style and the metal roller beneath it.

171. A chemical solution may be made as follows:

1 part of potassium ferricyanide;
30 parts nitrate of ammonium;
2 parts of water.

The following solutions for chemically sensitizing the paper tape for use in chemical telegraph receivers are given by Mr. G. B. Prescott in "Electricity and the Electric Telegraph":

Solution No. 1, nitrate of ammonia, 4 pounds; ferricyanide of potassium, 1 ounce; gum tragacanth, 4 ounces; glycerine, 4 ounces; water, 1 gallon.

Solution No. 2, nitrate of ammonium, 2 pounds; chloride of ammonium, 2 pounds; ferricyanide of potassium, 1 ounce; water, 1 gallon.

Solution No. 3, iodide of potassium, ½ pound; bromide of potassium, 2 pounds; dextrine or starch, 1 ounce; water, distilled, 1 gallon.

"Of the above solutions, No. 1 may be considered best for steady work on short circuits, and being also of comparatively high resistance, it is least affected by leakage from other lines. No. 2 is much more sensitive and can be made to record with the faintest trace of current; it is therefore well adapted for long circuits. No. 3 is highly sensitive and capable of the most perfect and beautiful work at an extremely high rate of speed."

CREHORE AND SQUIER SINE-WAVE SYSTEM.

172. Let the sine curve, Fig. 58 (*a*), represent a regular succession of simple alternating-current waves given to

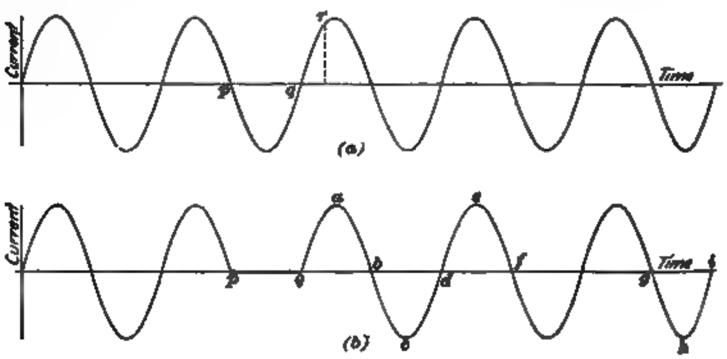


FIG. 58.

the line by an alternating-current generator. If the current passes through a key that may be opened or closed at

pleasure, then, provided the key previously closed is opened at a time corresponding to the point *p* of the wave upon the horizontal axis, the current that was zero at the instant the key was opened will remain zero in circuits that have resistance and inductance alone; again, if the key could be closed exactly at a time corresponding to the point *q* on the curve, also upon the axis, the current would resume its flow undisturbed according to the sine curve. The true current obtained by opening the key at *p* and closing it at *q* is shown in Fig. 58 (*b*), where the current remains at zero between these two points.

If the key had been closed at any other point than *q*, as at *r*, the current would not have resumed its flow according to the simple sine wave, but would give a succession of waves alternately smaller and larger than the normal sine wave for a very few alternations, after which it would practically coincide with the sine wave. Furthermore, if the key is opened at some other point than *p*, when, therefore, the current is not zero, a spark may be observed at the break, and it requires time for the current to fall to zero.

NOTE.—This description of the sine-wave system is taken from a paper presented by Messrs. Crehore and Squier to the American Institute of Electrical Engineers.

No spark is made in a transmitter adjusted to break the circuit at the exact times when the current is naturally zero. This makes it possible, if it is found desirable, to use comparatively large electromotive forces and currents on the line, for no matter what the maximum value of the current, it is made and broken by this plan with no sparking. It is also possible to use waves of high frequency upon the line, the upper limit obtainable from an ordinary alternator being probably much higher than can be utilized for telegraphic purposes.

173. If a receiver were used that could reproduce an exact trace of the actual waves sent over the line, the curve traced would resemble that represented by the heavy curve in Fig. 59. The sine wave continues uninterrupted to the

hen the key is opened and held open for one wave length pq, when it is again closed for a le h qr, then opened for one-half a wave length rs, closed a wave length st, opened for a wave length tu, closed half a wave length uv, opened for half a wave length vw, and finally closed. By this plan it is possible the ordinary Continental telegraph code, a dash being ted when two successive waves, a positive and a negative one, are omitted by keeping the key open, and a dot when a single half wave is omitted. The space between

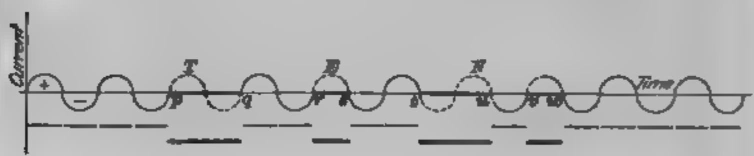


Fig 59.

parts of letters, as between the dot and dash of the letter n, is indicated by the presence of one-half a wave length, and the space between letters, as between t and e in the word "ten," by the presence of two half-waves, while the space between words may be represented by the presence of three half-waves, and between sentences of four half-waves, or more. The above is a single example, of which there are many, of a method of using alternating-current waves and shows how these signals may be interpreted by a fixed code.

174. A consideration of the time required to send the word "ten" by the above plan shows that it corresponds to the time of eleven half-waves of current. If we suppose that the frequency is an ordinary one used in alternating-current work, viz., 140 complete waves per second, the time required to send the word "ten" is .0394 of a second, or, by allowing three additional half-waves for the space between the words, the word "ten" would be sent just 1,200 times in 1 minute. There is no difficulty in using over some lines a frequency as high as 560 or even 600 periods per second. This would correspond to sending the word "ten" 4,800 and 5,143 times per minute, respectively. This limit in each

instance is only determined by the particular line used. (It is doubtful if these very high speeds could be obtained in practice even on short lines.)

175. It will be sufficient to show how any single half-wave may be omitted; for obviously any word or sentence may be formed by a repetition of this operation. Imagine one metallic brush bearing upon the smooth circumference of a metallic wheel and another metallic brush bearing upon the axle. One brush is connected through the armature of an alternating-current dynamo to the ground, and the other brush is connected to a line wire. The wheel and axle upon which the brushes bear are geared to the axle of an alternating-current dynamo and hence revolve in synchronism with it. If the periphery of the wheel is divided, for example, into 40 equal parts, and it is geared to run at one-fourth the speed of an armature that revolves in a field having 10 poles, each division thereof corresponds to one semicycle of the electromotive force produced by the generator. If both brushes remain continually in contact with the wheel and axle, the current transmitted will have the regular sine form represented in Fig. 58 (*a*); and for each revolution of the wheel there will be 40 half-waves, or 20 complete waves, transmitted. If one-fortieth of the circumference of the wheel is covered by paper or other insulating material, and the brush bearing on the circumference of the wheel is adjusted to ride on to and off this insulation just as the current is changing from one semicycle to the next, that is, changing its sign, while the other brush is in continuous engagement with the axle, the semicycle represented by the section covered will be suppressed, and without any sparking, even if the potential used is high. In practice, the brush bearing upon the circumference of the wheel is easily adjusted to this point by moving it slightly backwards or forwards around the circumference of the wheel until the sparking ceases; this adjustment having been once made, the brush is fixed in position. In each succeeding revolution of the wheel, this cycle of operation is exactly

repeated, and the current sent over the line will resemble that shown in Fig. 58 (*b*), having every fortieth semicycle omitted. It is only necessary to cover other similar sections of the circumference of the wheel in a predetermined order according to a code, or to draw a properly punched tape over the wheel without allowing it to slip, in order to transmit intelligence over the line.

It is seen that by this method of operating upon the alternating current, there is complete control of the individual half-waves of the current, which may be changing direction thousands of times in a second, far beyond the range of possible control by hand.

176. It has been shown by Crehore and Squier that theoretically two messages may be sent simultaneously by this method in the same direction or one in each direction over the same line. If by means of the sine-wave transmitter and light-polarizing receiver, which will be referred to later, 3,000 words can be sent in one direction over one line, then theoretically by duplexing the line 6,000 words may be sent per minute.

SINE-WAVE TRANSMITTER.

177. Messrs. Crehore and Squier have perfected a practical telegraph transmitter using an alternating sine-wave current, which is suitable for cable and land lines. It will operate their chemical receiver, the Wheatstone receiver, or a siphon recorder. The transmitting tape, however, is punched somewhat differently in each case. The following description is an abstract of a paper presented by them to the American Institute of Electrical Engineers in May, 1900.

178. In the present method of operating long cables, a dot is transmitted by a positive current obtained by connecting one pole of the battery to the cable and the other to the earth, and a dash by a negative current obtained by

connecting the opposite pole to the cable; the time required for a dot and dash is the same.

Several letters of the alphabet require two or more consecutive signals in the same direction, and in order to separate these successive signals at the receiver, it is usual to connect the cable to the earth during the latter portion of each individual signal. The electromotive force used in transmitting the letters *A*, *B*, and *C* is shown in Fig. 60 (*a*), where it is seen that the cable is connected directly to the

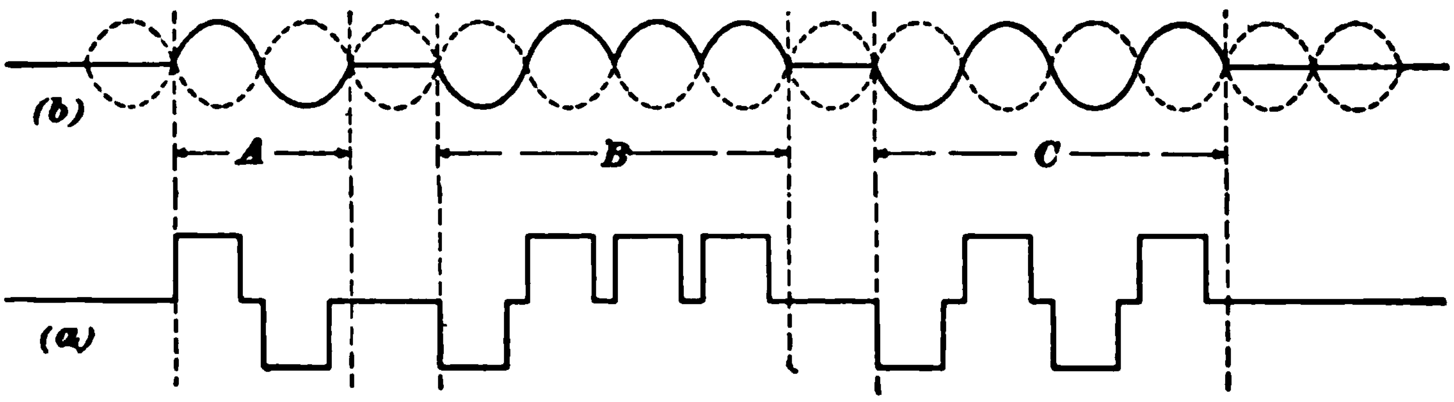


FIG. 60.

earth during one-fourth of each signal. This represents the form of electromotive force as furnished by the battery and transmitter; if no condensers were used, it would be the form of wave applied to the cable. But it is customary to use condensers at each end of the cable whether working simplex or duplex, and these condensers greatly modify the shape of the electromotive force that is applied to the cable itself.

179. It is important that a sine-wave transmitter should be used that will transmit to the cable the same combinations of impulses as those at present used in cable signaling, so that as far as the receiving station is concerned, no change whatever will be required, either in instruments or technical staff. In the sine-wave system, instead of the square-topped form of the electromotive force used for each individual signal at the transmitting end of the cable, as shown in Fig. 60 (*a*), each signal consists of a single sinus, or semiwave, of an alternating current, as represented in Fig. 60 (*b*).

The required combination of signals is produced ... of an alternating-current dynamo. A diagram of ...nator and cable transmitter is shown in Fig. 61. The ... rotates continuously, and a wheel W, geared to the ...nator shaft, feeds the paper tape T in synchronism with

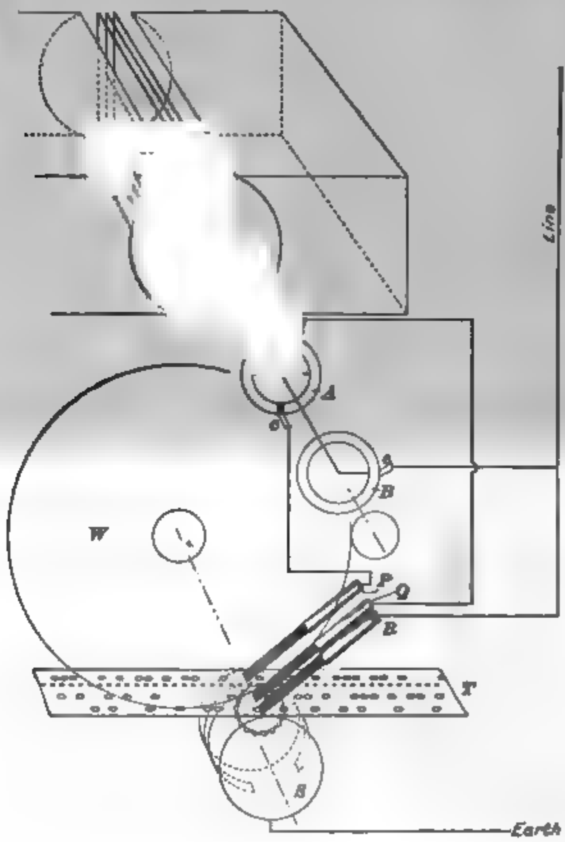


FIG. 61

the electromotive force generated, so that one semiwave of electromotive force is generated during the time that the tape is advancing a distance equal to the distance between the centers of two consecutive feed-holes. The transmitting tape is similar to the ordinary tape, having a row of

perforations on one side of the feed-holes to transmit dots, and on the other side for dashes. Brushes are used for making contact through these perforations, and by making the holes a proper size, the duration of contact can be made equal to the whole or any portion of the semicycle desired. The two brushes for transmitting the signals are on the same line transversely across the tape, and each brush *P* and *Q* is connected to one terminal of the armature winding through the brushes *c* and *d* and a divided ring *A*, which causes pulsations of the electromotive force supplied to each transmitter brush *P* or *Q* to consist of successive semisinuses in the same direction. A continuous ring *B* is also supplied, which connects the middle of the armature winding by means of the brush *e* to the line. The contact roller *S*, upon which the three brushes *P*, *Q*, and *R* bear, is connected to the earth or to a return wire. Thus it appears that whenever contact is established on the dot side of the tape between *P* and *S*, a positive sinus is transmitted to the line; contact between the brush *Q* and the roller *S* on the dash side sends a negative sinus.

181. Perforated Tape.—Earth connection is provided between letters and words by adding to the tape another row of holes and supplying a third brush *R*, which connects the line directly to earth whenever a perforation

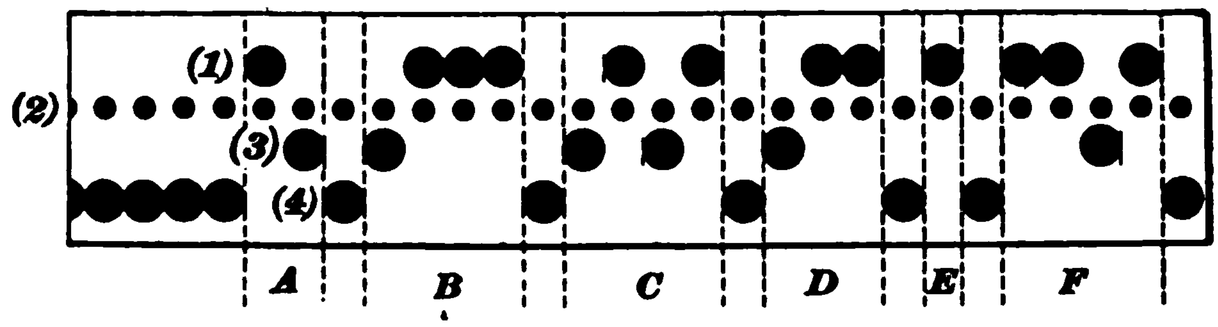


FIG. 62.—*Sample of transmitting tape, showing letters A, B, C, D, E, and F.* (1) *is the dot row.* (2) *is the feeding row.* (3) *is the dash row.* (4) *is the space row for earthing the cable between letters and words.*

occurs under this third brush. A sample of the transmitting tape is shown in Fig. 62, where the letters *A*, *B*, and *C* are represented. The three-hole tape, or four-hole tape counting the feeding row, is prepared on a perforator that differs from the ordinary form only in the arrangement of the

punches. The operator can detect no difference between its action and that of the ordinary Wheatstone perforator.

182. Adjustment of Brushes.—Evidently, to send a simple alternating current to line with this transmitter, it is not only necessary to perforate the tape properly for dots and dashes, but the brushes must be so placed that contact through the perforations will take place at the instants when the current is approximately zero, otherwise there will be a disturbance that will distort the wave from its true sine form. To adjust the brushes easily, they are both mounted upon the same carriage, which is adjustable along the tape by means of a micrometer screw. This adjustment should be made by receiving a current (sent by means of a tape properly perforated to transmit the full alternating current) on a local siphon recorder connected in a circuit with the cable to be used, and not merely in a local circuit. The brushes are properly adjusted when the record is a smooth sine wave.

183. One peculiarity met in designing an alternating-current dynamo for working long cables is the low frequency required, which, for an Atlantic cable, is as low as 3 or 4 per second, while the ordinary frequencies of alternators for lighting and power circuits vary from 25 to 150 per second.

One of the radical features of the transmitter is the use of small steel brushes that make contact through the perforations in the tape with a platinum cylinder having a corrugated surface. In using the alternating current, always interrupted at the zero point, there is not the same objection to the use of brushes due to sparking that is the case when a direct current is suddenly broken at a high voltage. Any system of levers, such as is used in the Wheatstone automatic transmitter, is impossible for very high-speed telegraphy.

184. A large number of experiments with this transmitter were performed upon the cables of the Commercial Cable Company. To make a comparison between the automatic battery transmitter of the Cuttriss pattern, as used

by the Commercial Cable Company, and the Crehore-Squier sine-wave transmitter, observations were taken with each instrument under the same conditions of the circuit, the recorder having the same adjustment in each case. The cable was used, as in regular working, with the duplex arrangement. The battery used consisted of Fuller primary cells, and measured 36 volts on open circuit.

185. Amplitude of Siphon Signals.—With this voltage the double amplitude of the excursions of the siphon were about .11 inch at a frequency of 3, and decreased to .015 when the frequency increased to 5.6 periods per second. Below a frequency of about 4.3 waves per second, the sine-wave transmitter produced siphon records having a smaller amplitude, and above 4.3 waves per second, a larger amplitude, than any other form of transmitter.

186. Influence of Electromotive Force on Speed of Signaling.—The speed of signaling or the number of letters per minute that can be transmitted and received by a given set of instruments on a submarine cable depends on the magnitude of the electromotive force as well as on the shape of the wave. The speed is not proportional to the voltage by either method, but the increment becomes less and less as the pressure is increased, until it may be necessary to double the voltage to gain a few letters per minute.

187. Limiting Electromotive Force.—There is a practical limit with any particular cable to the voltage, which it is not profitable to exceed, since the gain in speed is so slight. The limit of voltage that it is profitable to use is not the same for the sine wave as for the battery method. To obtain the best speed with either system it should be worked at this maximum voltage point, which limit can only be determined by experiment. Before such a limit is reached, however, there are often other causes that prevent the best voltage from being used. If a fault develops, a high potential at that point might effect the complete interruption of the cable. When the fault is discovered,

it is customary to reduce the voltage to prevent entire interruption. There is at present such a fear of using high voltage on submarine cables that a limit is set to the pressure at which cables may be operated, and this limit, for most of the cables of the world, is little more than 50 volts.

Since the voltage is limited upon a cable, it is evident that the system which can furnish the higher speed at the same pressure has the advantage, or that system which can furnish a given working speed with the lowest voltage is the safest one to use.

188. With battery transmitters, the maximum pressure to which the cable itself is subjected is approximately equal to the battery voltage, whether condensers are used or not. The difference is that with condensers this pressure is momentary, while without them it is more continuous. It should further be stated that a sine-wave electromotive force that has an amplitude of 1 gives a reading of only .707 on an electrostatic voltmeter. This reading is known as the *virtual* electromotive force. Hence, a sine wave that produces an electrostatic voltmeter reading of 35.4 volts between the cable and earth is equivalent to a battery of 50 volts, whether applied to the cable directly or through condensers, because the two have the same maximum values.

189. Gain in Speed at Same Voltage.—The received waves through a long submarine cable are approximately sine waves, whether true sine waves or merely battery reversals are used at the transmitting end. With the same maximum voltage at the transmitting end of the cable, however, the amplitude of the wave at the receiving end is greater when the sine wave is used, which means that more energy is transmitted by the cable. This is equivalent to attaining higher speed, since with the same speed as with the battery transmitter, the amplitude of motion and definition is greater; but by tightening the suspensions and quickening the natural period of the recorder, the same definition and amplitude is obtained at a higher speed.

190. The **advantage** of this transmitter is therefore the increase in speed that may be obtained with its aid over cables, and especially over long lines where higher frequencies may be used on account of the smaller electrostatic capacity. This increase in speed is partly due to the use of a higher voltage, since with a battery transmitter like the Wheatstone or Cuttriss, voltages over a certain value are impossible owing to the sparking at the contacts, the line currents being interrupted at full strength; whereas, the sine-wave transmitter uses alternating currents that are interrupted only at the zero instants, whatever electromotive force is used. A trial made between London and Aberdeen without repeaters showed that the limiting speed was 107 words per minute with the ordinary Wheatstone transmitter, and 195 words per minute with the sine-wave transmitter, using an electromotive force of only 230 volts.

191. In telegraph stations where a number of sine-wave transmitters are used simultaneously, there need be but a single alternating-current dynamo for the whole station, and a separate small synchronous alternating-current motor at each desk, the sole duty of which is to draw a paper tape under contact brushes in step with the impulses of the generator. The single alternator not only drives the synchronous motors, but also supplies the line with alternating currents through the contact brushes. The present tendency in telegraphic engineering is to remove all forms of primary batteries as a source of power, and the sine-wave alternator combines this advantage with the most efficient form of wave for signaling.

CREHORE AND SQUIER CHEMICAL RECEIVER.

192. According to Crehore and Squier, the use of a sine-wave alternating current permits of greater potentials being realized in a chemical receiver with less disturbing influence from the line than would be the case if a constant direct electromotive force was used. By using a sine-wave

alternating current with a single needle and a plate as electrodes, the record shows a regular succession of distinct marks separated from one another by equal intervals. Each mark exhibits an intensity varying approximately according to the sine curve. Since by this arrangement the current makes its record in one direction only, the result is that alternate semicycles of the current are suppressed and alternate ones are recorded

By receiving with two needles side by side, all the alternations are recorded, those that were suppressed before now appearing at the second needle. The record then appears in two parallel lines of marks, marks appearing in one line opposite spaces in the other. The marks that appear in one line represent dots, those in the other line dashes. In their chemical receiver, the record is made in lines across a page instead of in one continous line, which requires a long tape that is inconvenient for some purposes.

193. The Crehore and Squier instrument may be used as a transmitter or as a receiver, and will transmit messages from sheets upon which they have been perforated in lines transversely on the sheet and also receive the messages in lines transversely on a sheet. The messages will then be in letter form. Another object of the invention was to construct a receiver that would be especially adapted to take messages sent by the alternating sine-wave current transmitters constructed by them. The receiver may not, however, be used only with the latter transmitters, since it may be readily adapted for use in the place of any chemical receiver.

194. In this receiver the styles, or contact points, are made to travel across the paper or message sheet, and the sheet is also made to travel under them. The paper may be in the form of sheets or in a continuous web. The message sheet may be made to travel step by step, being stationary, while the styles are making a trip across it and moving a line space between the trips of the styles, in which case the styles would move straight across the sheet; or the

sheet may have a continuous movement, in which case the styles may be made to move obliquely across the machine, their speed with relation to that of the sheet being so timed that the paper will have advanced a line space between successive styles and the line of characters will be nearly straight across the sheet. This latter construction is the one preferred, and, therefore, the one illustrated.

This apparatus is shown in Fig. 63. In the frame of the instrument is a roller *6*, which is, in a sense, a "platen," and may be so termed. It is formed of a metal tube of tin or nickel, or plated therewith, and is mounted upon and suitably insulated from the frame in which the journals of the rollers are secured. When the platen is a conductor, the apparatus may be used either on an alternating-current circuit or on a direct-current circuit. When so used, the platen may be placed in circuit by a brush *7*. The chemically prepared or sensitized paper is made up in a roll and mounted in one end of the frame, as indicated at *8*. From this roll the paper is led over the cylinder *6*, around a suitable guide roll *9*, and out through feeding rolls *10* and *11*, the paper being shown at *12* as it comes out of the instrument.

195. In the form of instrument here shown—that is, one adapted to receive messages from an alternating-current transmitter—two styles, *13* and *14*, are secured to the conducting tapes *16* and *17*, respectively. The conducting tapes are in the form of endless bands and mounted upon rollers, or drums, *18* and *19* journaled in suitable brackets, or bearings, at either side of the apparatus. The metallic rings *20* and *21* are suitably constructed and insulated from one another, so that each may receive and be in electrical contact with one of the conducting tapes. These rings have flanges, or projections, extending to the face of the pulley, so that contacts, or brushes, *22* and *23* may bear thereon and convey the current through the rings *20* and *21* to the metallic bands and the styles while in motion.

Several pairs of styles *13* and *14*, mounted upon the same

bands, are placed equal distances apart, and these intervals are such that one pair will engage the message sheet just

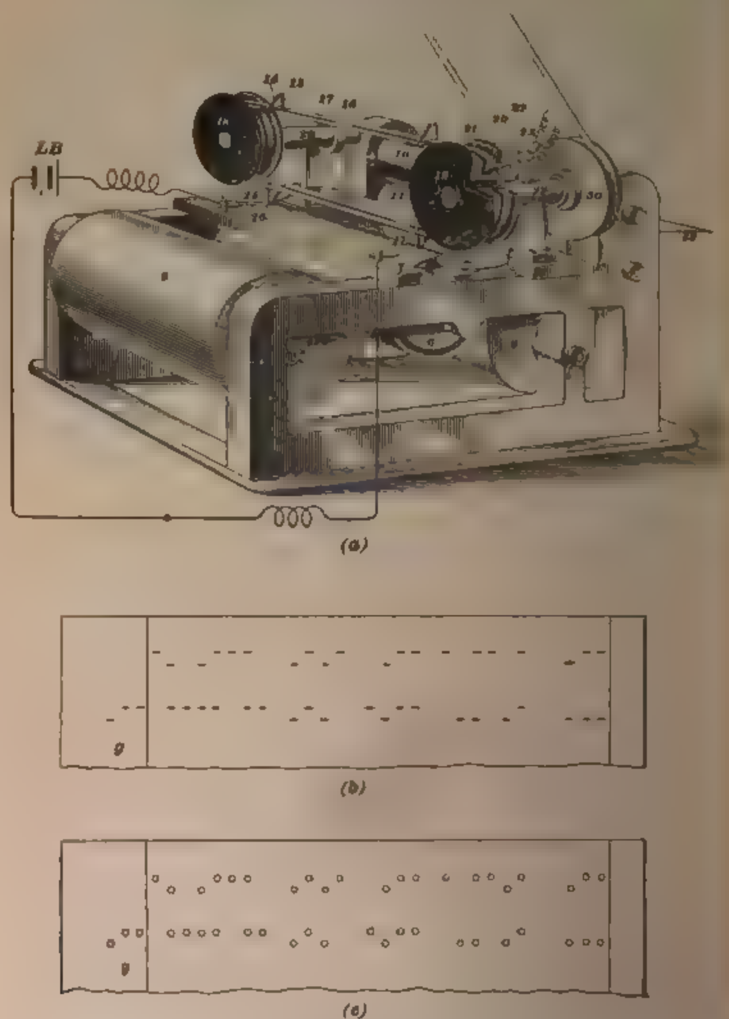


Fig. 63

before the preceding pair leaves it, whereby it will be impossible for the apparatus to omit any character. The

current flows from one style to the other through the message sheet, and as the alternations occur, a mark is made at one needle, then at the other, the cessation of current or the periods of zero current between alternations or semicycles producing no mark upon the sheet.

The styles are led on to and off the paper by means of disks *24* and *25* of insulating material. These disks insure a steady and perfect contact between the styles and the paper as they come upon the latter and, likewise, a smooth and steady movement upon leaving the paper, even when traveling at a high speed. These disks also serve to determine the margin of the sheet on which the messages are received.

196. In providing for the presence of two sets of brushes upon the paper just before the preceding set leaves the same, the repetition of a portion of a character or signal will frequently be produced. This repetition, however, is readily discernible; but for the purpose of making it absolutely clear where such repetition terminates, longitudinal lines may be produced upon the sensitized paper to indicate the actual limits of the lines of characters. These lines may be made by marking devices as the paper is passing through the apparatus. These marking devices consist of steel needles *26* and *27* in an electric circuit containing a battery *L B*. The needles are mounted upon the frame of the machine and bear upon the paper as it passes over the platen *6*. These marginal lines are produced by electrolysis, and in this figure the character *g* is shown as repeated. This figure also illustrates the appearance of the characters upon sensitized paper.

The driving pulley *30* is driven by a belt from a suitable motor. The movement of the paper through the apparatus is accomplished by means of a worm (behind the pulley *30*, and therefore not shown in the figure) mounted, with the driving pulley *30*, upon the shaft *29*. The worm meshes with a worm-wheel mounted upon the shaft of the feeding roll *10*. The brackets supporting the shaft *29* are so

mounted that the styles *13* and *14* travel obliquely across the apparatus, and their point of leaving the paper is a line space from the point at which they engage the paper. The movement of the paper is so regulated with relation to the speed of and obliquity of movement of the styles that the lines of characters are parallel and extend across the sheet at right angles to its lateral edges.

197. In using this apparatus for receiving messages over a direct-current circuit, the marks will appear at one style, the current passing from one style through the paper to the other, or by the omission of one style it may be made to pass from the remaining style to the roller *6*. In each character represented on the message sheet in Fig. 63 (*b*), the upper dots or dashes are made by, say, the positive semicycles, while the lower ones are made by the negative semicycles, the intervals between dots or between dashes representing the brief periods of zero current, and the spaces between the characters or words representing the semicycles that have been suppressed by the transmitter plus the brief period of zero current between the end of one signal and the beginning of the next. Obviously, the apparatus described is not limited to the receipt of any particular style or character of signal, but may be used with any of the existing codes.

198. As a Transmitter.—To use this instrument as a transmitter, the messages are prepared as indicated in Fig. 63 (*c*), wherein perforations are made across a sheet of paper or other suitable non-conducting material, as shown. The message sheet thus prepared is fed over the platen, and as the styles ride across the sheet, they make circuit with the platen through the perforations, the circuit being interrupted as the styles ride over the portions of the sheet between the perforations.

To render a transmitting sheet operative with the alternating current, the brushes must move in synchronism with the alternations of the current, and the brushes or the parts carrying them must be made adjustable with respect

to the perforations in the message sheet, so that the makes and breaks in the current flowing over the line will occur at the zero points between the pulses or alternations of the current.

199. Messrs. Crehore and Squier, while working with their sine-wave transmission, developed an entirely new type of receiver, called a *light polarizing receiver*, having no inertia in the recording mechanism. No difficulty was experienced in sending and recording messages by the use of their sine-wave transmitter and light polarizing receiver at the rapid rate corresponding to between 3,000 and 4,000 words per minute. However, their elaborate light polarizing receiver is hardly a practical telegraph instrument, and hence will not be described here. A description of it, with interesting experiments relating to their system, will be found in Vol. XIV of the Transactions of the American Institute of Electrical Engineers.

200. Sine-Wave Transmitter and Wheatstone Receiver.—The sine-wave transmitter can operate the Wheatstone receiver approximately three times as fast as the Wheatstone transmitter on any line, provided the mechanical limit of the receiver, which is about 600 words per minute, is not already reached. Furthermore, it has been worked on circuits that ordinarily require two repeaters, without any repeaters, and at any speed up to the mechanical limit of the receiver. From the numerous experiments that have proved the foregoing statements, it seems probable that the sine wave possesses superiority over other forms of current wave for any speed, slow or fast. There are two causes that account for the slower speed of the Wheatstone transmitter, namely, the difference in wave lengths sent into the line by the transmitter and the departure from the sine form of wave. Another cause for gain in speed by the sine-wave transmitter is the fact that a higher voltage may be used with it than with the Wheatstone transmitter, although it is difficult to estimate the precise amount of gain due to this fact. The sine-wave transmitter and Wheatstone receiver will work

successfully on a line $1\frac{7}{10}$ times as long, at the same speed as the Wheatstone system, provided the mechanical limit of the receiver is not exceeded. With copper wire weighing 800 pounds to the mile, the sine-wave transmitter can operate to the limit of the Wheatstone receiver any distance less than 1,800 miles, while the Wheatstone system using the same wire can operate to the same limit any distance less than 1,260 miles.

201. Wheatstone Receiver Shunted by a Condenser.—When the Wheatstone receiver is used in connection with the sine-wave transmitter, it is possible to increase the receiver current materially, making it even larger than the line current, by connecting a condenser of proper capacity around the receiver. By knowing the inductance of the receiver and the frequency, the capacity of the condenser that should be used to give the best results can be calculated by the formula

$$Q = \frac{1}{L(2\pi n)^2}, \qquad (2.)$$

in which Q = capacity of condenser;
L = inductance of receiver;
n = frequency;
π = 3 1416.

From this it is seen that the capacity of the condenser should vary inversely as the square of the frequency n, although the value of the capacity for any frequency is not very critical; that is, a given condenser will improve the working for a considerable range of speed.

POLLAK-VIRAG TELEGRAPH SYSTEM.

202. The method of high-speed telegraphy devised by Pollak and Virag, of Austria, has excited considerable attention. Experiments made over a metallic circuit 400 miles long, having a resistance of 4,000 ohms, and using a battery

of 20 volts gave clear signals, both in wet and dry weather, at a speed of 70,000 words per hour, while with 25 volts a speed of 100,000 words per hour was attained. Other experiments on a metallic circuit of iron wire 210 miles long and of 6,000 ohms resistance was also successful, a speed of 54,000 words per hour being obtained with a 60-volt battery. Trials between Budapest and Berlin, in the fall of 1899, gave distinct and readable signals at speeds of from 1,300 to 1,500 words per minute.

203. Advantages and Disadvantages.—This gives of course a great improvement in speed over ordinary telegraphy, but it is likely to prove that while the actual sending of the electrical signals is much faster than the common methods, the advantage will be lost in a great measure, if not fully offset, by the time and complication of making the messages ready for the wire and of translating them into a written language at the receiving end. The telegram must first be changed into the characters of the Morse system and the tape perforated, as in the Wheatstone system. After reception, the photographed strips must be developed and then translated into ordinary language. It is thought that this complicated manipulation may lead to many errors in transmission. This has been found to be the great objection to many high-speed systems heretofore, and is the reason why the Wheatstone system is in comparatively restricted use in this country.

204. The following is an abstract of the descriptions of the Pollak-Virag systems and apparatus that appeared in the London "Electrician," during 1899 and 1900. The transmission is effected by a perforated strip of paper, as in the case of the Wheatstone automatic system, and a telephone fitted with a small concave mirror serves as the receiver, the diaphragm of the telephone being set into oscillation corresponding to the current impulses generated by the transmitter. These oscillations are made visible photographically. The dots and dashes of the Morse code

represented by strokes on either side of the central line, as shown on the cylinder *H* in Fig. 64 (*x*), the strokes being produced by current impulses in reverse directions. The transmitting apparatus *T* consists of a roller *a* driven by a motor or clockwork. The perforated paper is drawn over the metal roller *a*, which is connected to one of the line wires. The strip of paper *b*, shown in (*z*), is perforated

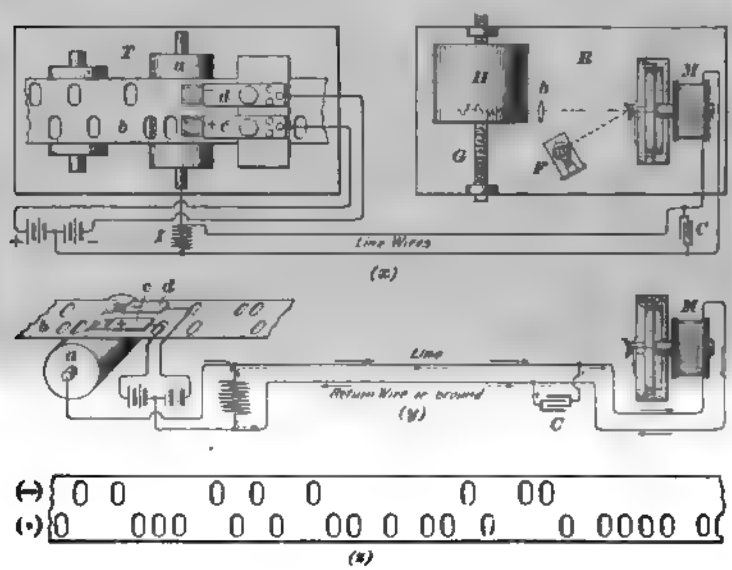


Fig. 64.

in two lines corresponding to the two directions of the current. Above the tape two brushes *c* and *d* are fixed, one connected to the positive pole and the other to the negative pole of the battery. The return wire or ground is connected to a point at the middle of the battery. Now, if in consequence of the perforations of the paper, either one of the two brushes comes into contact with the metal roller, either a positive or negative current flows through the roller to the line and thence to the receiving apparatus.

205. At the receiving station R, the currents pass through a telephone M whose diaphragm is moved in a direction determined by the direction of the current impulse. The movements of the diaphragm are transmitted to a small mirror with the assistance of a metal rod. It is necessary that the small movements of the diaphragm should occasion a relatively large displacement of the mirror. This is done by fastening to the mirror a small plate of soft iron, held in position by one

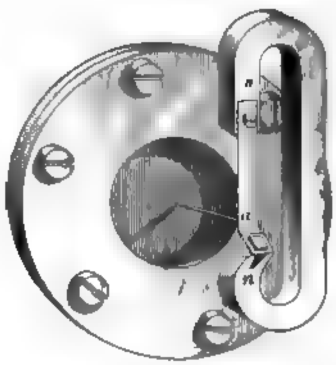


FIG. 65.

pole of a permanent magnet, about as shown in Fig. 65. The pole n of the magnet ends in two points and holds the mirror in such a way that the line joining these two points is the axis about which the mirror turns. The other pole s of the magnet is provided with a weak spring a, which forms the third point of support for the mirror. This spring a is connected to the diaphragm by means of a small rod, so that the small movements of the diaphragm cause a motion of the mirror, which is relatively large, as the points of support of the mirror, the two on n and the one on a, are very near to one another. This method of magnifying the movements of the diaphragm has the advantage that, in consequence of the small weights of the moving parts, the velocity of vibration of the diaphragm is not lessened.

The light of a small incandescent lamp falls on the small concave mirror just mentioned, which throws the image of the filament on a piece of paper sensitive to light. In front of this sensitized paper, a cylindrical lens b is placed that focuses the reflected beam of light so as to produce a bright spot upon the paper. In consequence of the current impulses that move the diaphragm and mirror, the spot of light moves out of its original position in one direction or the other. In this way the up-and-down strokes, representing

letters, as shown in Fig. 66, are traced on the sensitized paper. The latter (see Fig. 64) passes over a drum *H* that moves horizontally on a screwed spindle, so that the line

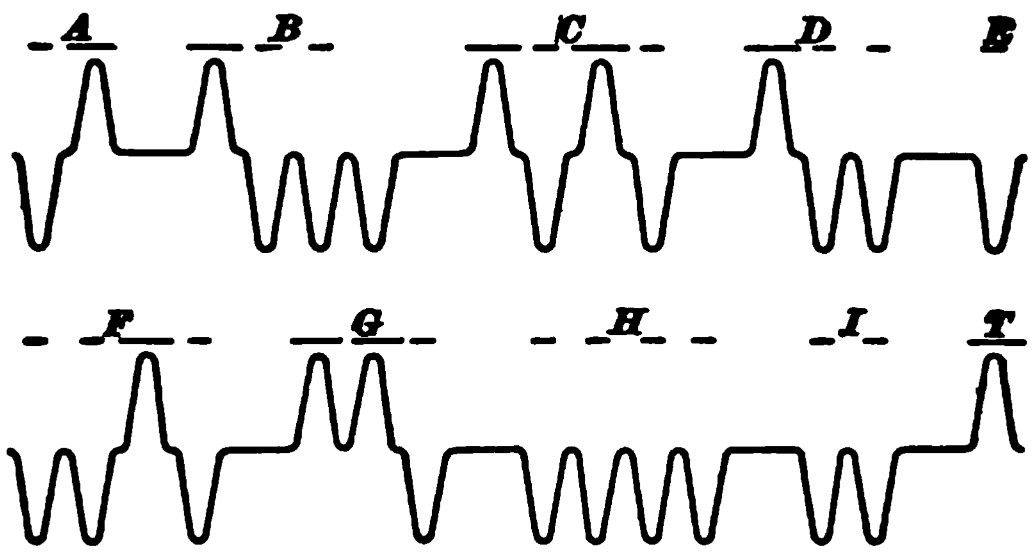


FIG. 66.

traced by the spot of light follows a continuous spiral route. The amplitudes of the movements of the spot of light are large enough to make the signals clearly legible.

206. Although this action appears simple enough, allowance has to be made for one important disturbing factor, viz., the natural period of oscillation of the diaphragm itself. This is done by making the duration of each current impulse equal to the natural period of the telephone diaphragm, so that the current always stops exactly at the moment when the diaphragm swings back to its original position. By suitably adjusting the velocity of the paper and the dimensions of the perforations, the duration of an impulse can be regulated and a perfect damping of the membrane so obtained. But in order not to be dependent in practice on the precision of the movement of the paper, another device has been added. In Fig. 64, the condenser *C*, which is connected in parallel with the telephone, will be charged as long as the current impulse lasts, but after the current ceases, the condenser will discharge into the telephone circuit. Hence, if the current impulse is shorter than the natural period of the vibration of the diaphragm, the discharge from the condenser will prolong the duration of the current, and *vice versa*. By using a condenser of suitable capacity, the diaphragm may be made to

return to its original position without first oscillating to and fro.

It appears that the inventors have not overlooked the fact that the properties of the line, independent of the apparatus, render high-speed telegraphy difficult. An endeavor is made to counteract this influence to some extent by connecting, parallel to the line at the transmitting station, a coil l having self-induction, whose dimensions are chosen according to the self-induction, capacity, and resistance of the line.

207. Fig. 65 shows the most recent type of diaphragm and mirror connection, while Fig. 67 gives a good idea of the arrangement of the parts of the complete receiving

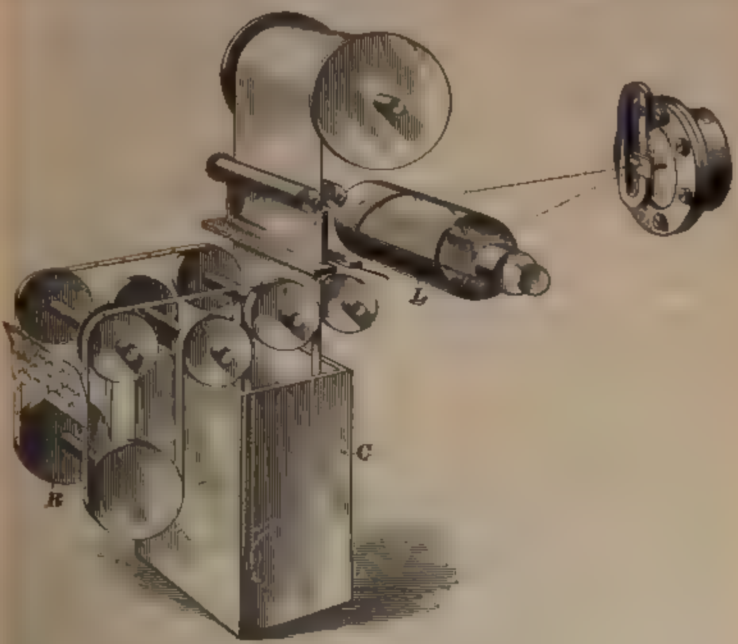


FIG. 67.

apparatus. By this apparatus, messages are received and recorded in zigzag lines running from left to right on a broad strip of sensitized paper. This left-to-right movement is produced as follows. The source of light is a

glowing filament that is surrounded by the cylindrical metal mantle *L*. In this mantle a helical slit is cut, the helix making one complete turn. In consequence, when the mantle is turned about its axis, the source of the light falling on the mirror moves uniformly from right to left, and, hence, the spot of light formed on the paper by reflection from the mirror moves uniformly from left to right. A series of motions of the mirror about a horizontal axis is recorded, therefore, on the paper as an up-and-down zigzag line running from left to right, and commencing at the left end of a new line upon the completion of every filled one. On the commencement of a message, the revolution of the helically slit mantle and of the sensitized paper feeder *R* is automatically started. At the close of the message, the paper strip is cut and the movement of the unexposed paper stopped, while the exposed strip is carried forwards by clockwork into the developing bath *C*, then into a neighboring fixing bath, and is finally pushed through a slot in the outer cover of the apparatus.

POLLAK-VIRAG WRITING TELEGRAPH.

208. The apparatus shown so far yields only the zigzag writing resembling that of a cable siphon recorder. For the recording of a message in the characters of ordinary handwriting, a double receiving apparatus, shown in Fig. 68, is necessary. This differs from the receiver already described in having two telephones and one concave mirror supported upon one fixed point and two movable points. One telephone

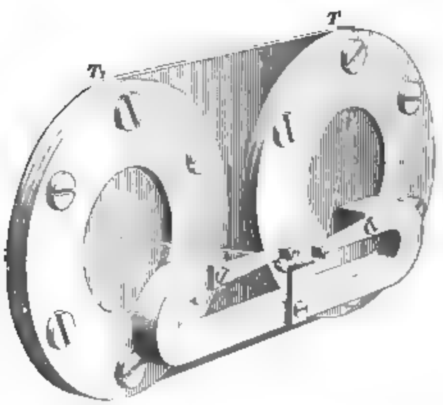


FIG. 68

moves the mirror about a horizontal axis, the other about a vertical axis, so that by acting simultaneously the two telephones can cause the reflected spot of light to trace any desired curve. The arrangement of transmitting and receiving apparatus, which will be explained presently, is shown in Fig. 69. Two line wires L and L_1, in addition to an earth return, are now necessary. One telephone T_1 is connected in a loop with these two line wires, that is, in series with them; the other telephone T is connected between the loop and the earth. For producing horizontal

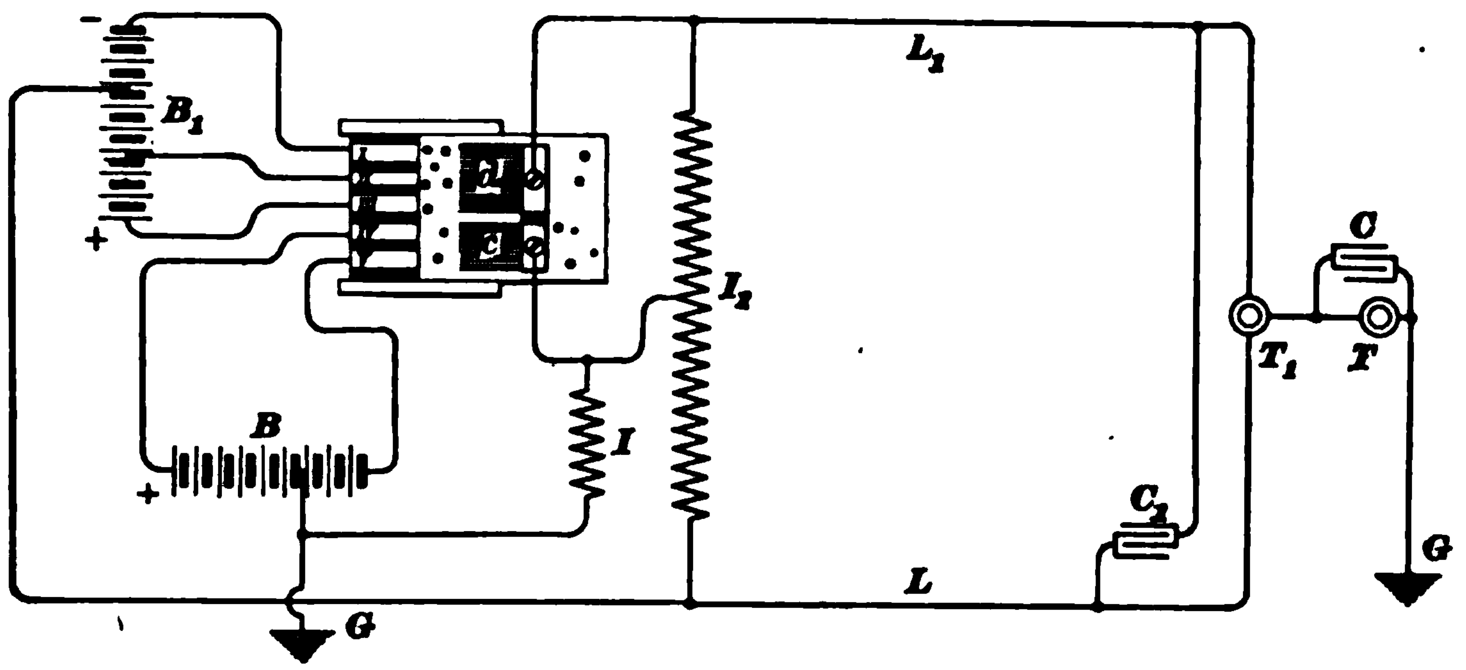


FIG. 69.

motions, a positive current and a negative current of approximately equal strength are required; for the vertical movements, a positive current, an equal negative current, and a positive current of double their strength are required. These current impulses produce motions to left and right and up-and-down motions of equal amplitude, and a downward motion of double this amplitude. Fractions of this amplitude are obtained by shortening the duration of the contact at the sending end.

209. The transmitting apparatus shown in Fig. 69 consists of a perforated paper strip, five slip rings connected to the batteries, and two brushes connected to the line. The size of the holes in the paper determines the duration of the contacts between the brushes and rings.

210. If the ordinary written Latin characters be dissected, it will be found that certain of them, such as *m*, *v*, *p*, as shown in Fig 70, can be resolved into elements each consisting of a down and an up stroke commencing and ending at the same height above the line The letter *m* consists, for example, of three such elements, the letters *v* and *p* each of two. In order to cause the receiver to write letters that can be analyzed in this way, the currents sent from the sending end to produce vertical movements in the receiver are regulated with respect to direction, intensity, and duration. This is done for these three letters by perforating the paper-transmitting strip with larger or smaller holes in two rows, as shown. The elements are so combined and spaced as to produce the letters distinctly and in the order desired.

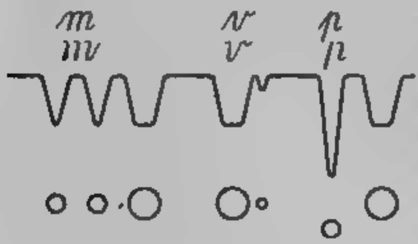


FIG. 70.

211. For letters extending above the top of an *m*, there are three rows, *I*, *II*, *III*, of holes, as shown in Fig. 71, corresponding to the three rings under one brush. A hole in row *I* exposes to the brush *d* (see Fig. 69) the ring *I*, supplying a negative current of known voltage, a hole in row *II* exposes ring *II*, supplying a positive current of equal voltage, and a hole in row *III* exposes ring *III*, supplying a positive current at double that voltage. The effect on the mirror of the receiver of holes punched as in Fig. 71 is shown directly above the plan of the perforations. It is a matter of trial to fix on that size of hole which

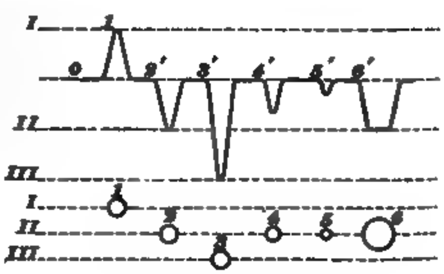


FIG. 71.

allows just sufficient time for the current to exercise its full effect on the telephone. A larger hole then merely broadens the loop that the spot of light traces on the moving sensitized paper; while a smaller hole displaces the spot of light a distance that is only a fraction of the full amplitude.

212. But the written Latin characters include many composed partly or wholly of closed curves, and these cannot be written by the mere up-and-down movements so far described; properly timed to-and-fro horizontal motions are necessary in addition. Such letters are therefore resolved into and compounded from vertical and horizontal components. The movements of the receiver corresponding to each of these components are each produced by separate current impulses, and the time intervals between these impulses are chosen and obtained by deciding on the spaces to separate consecutive holes in the perforated tape.

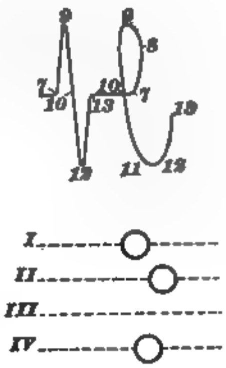


FIG. 72.

Take, for example, the letter *l*, which contains a closed curve, or loop. Its vertical components, merely, are written by the mirror as in the left-hand portion of the diagram in Fig. 72. This up-and-down zigzag is the result of impulses sent into the line through the perforations in the rows *I* and *II*, acting alone. The hole in row *I* would cause the V-curve *7–9–10* to be described on the moving paper; the hole in row *II* would produce the curve *10–12–13*. But when a hole, as shown in the figure, is punched in the row *IV*, so that a current deflecting the spot of light from right to left is sent into the line, as soon as the spot of light in its upward motion due to hole *I* reaches the place marked *8*, a deviation to the left is produced—in spite of the forward movement of the paper—which carries the spot of light to *9*. Here the current through the hole in row *I* ceases, and the spot of light returns to *10*, where it is immediately, in consequence of the coming of the hole in row *II*, given a

downward motion toward *11*. Here the effect of the hole in row *IV* dies out, and the mirror, in restoring itself to its normal position, then writes on the moving paper the broad loop *11–12–13*. Thus the second of the two telephones, by

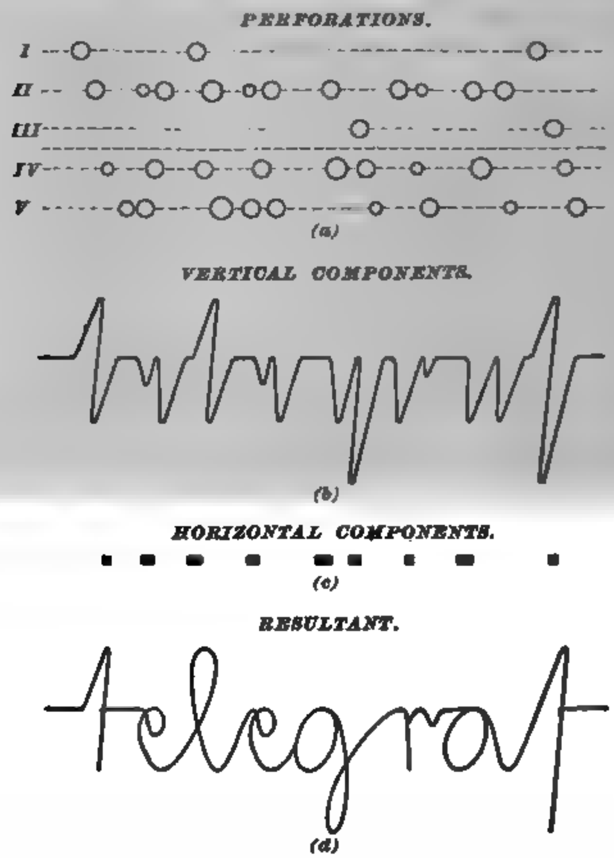


FIG. 78.

its production of horizontal to-and-fro motions of the mirror, makes it possible to write letters containing closed curves.

In this manner any character of the alphabet can be written. The character must be analyzed at the sending end into its horizontal and vertical components, as defined above, and compounded at the receiving end by the two

telephones. The telephone T_1, Fig. 69, gives the spot of light the vertical motions caused by holes in rows *I*, *II*, *III*; the telephone *T*, the horizontal motions demanded by the holes in rows *IV*, *V*. The construction of the complete word "telegraf" on these principles is shown in Fig. 73. Fig. 73 (*a*) gives a plan of the perforations in the sending strip; (*b*) gives the written record due to the telephone T_1 operated from the rows *I*, *II*, *III*; (*c*) represents the effect on the telephone *T* of the holes in rows *IV*, *V*; and (*d*) is the resultant of the vertical and horizontal components.

213. The sources of current are two comparatively small batteries connected to the rings, line, and earth, as shown in Fig. 69. From battery B_1 are taken equal negative and positive currents corresponding to rows *I* and *II* of the perforated paper, and also a positive current of double the value corresponding to row *III*. From battery *B* are taken a strong positive current for the leftward deflection of the spot of light and a weak negative current for the rightward deflection. It will be noticed from this diagram that, as before mentioned, only the telephone T_1 is included in the loop of the double line, the telephone *T* receiving its impulses after they have passed as two oppositely directed currents of equal strength through the telephone T_1; in other words, T_1 is differentially wound and is not affected at all by equal currents that flow in both line wires *L* and L_1 in the same direction and return through the earth to the sending station.

214. The self-induction and the capacity of the wires and the effects of the natural oscillation periods of the telephone diaphragms are compensated for by coils and condensers as shown in Fig. 69, where I_1 and *I* are inductance coils and C_1 and *C* are condensers. By modifying the condenser *C*, moreover, the difference between the horizontal and vertical motions can be adjusted to a certain extent. The perforating of the paper sending strip is accomplished by a simple machine that punches simultaneously all the holes corresponding to any required character.

There is in this system of telegraphy no need for the synchronizing of the sending and receiving apparatus, for variations in the speed at either end merely broaden or narrow the letters; and, therefore, the inventors claim that this system is simpler and considered more reliable merely from this point of view. With the aid of a distributor (such as Delany's) it is claimed that about 30 sets of apparatus could be arranged to work on one line. At a recent trial, allowed by the Hungarian Minister of Commerce, most excellent results were said to have been obtained over two pairs of telephone wires from Budapest to Pozsony and back, a distance of nearly 230 miles. The rate of transmission—at which rate very good writing was produced—reached 1,000 words per minute through a resistance of 2,000 ohms.

PRINTING TELEGRAPHS.

215. Telegraph systems that record the transmitted signals in plain Roman letters upon a moving tape or a sheet of paper are called **printing telegraphs.** The problem of automatically recording telegraph messages in Roman type is one that has fascinated inventors almost from the days of Morse. Printing telegraph systems have been used more or less since about 1856, and on account of constant improvements there are more of them than it is practical to describe. Mr. Royal E. House invented a type-printing telegraph that was in successful operation in this country in competition with the Morse and Bain systems prior to 1857. The systems that are used in the large cities for reporting stock quotations, race-track news, etc., are commonly known as *stock-ticker systems.* The Phelps printing telegraph is used on several main-line circuits by the Western Union Telegraph Company. In some of the European countries and on the English Channel cables, the Hughes type-printing telegraph, or modifications of it, and in France, the Baudot type-printing telegraph systems, are used.

The French system of Emile Baudot and the American system of Professor Rowland use an arrangement for dividing the use of the line among several operators, resembling in this respect the Delany multiplex system.

PRINCIPLE OF PRINTING TELEGRAPH SYSTEMS.

216. Almost all printing telegraphs depend on the synchronous rotation of the transmitting and receiving mechanism, but the methods used for accomplishing this vary considerably.

Imagine two toothed wheels synchronously propelled by clockwork or like those used in the Delany synchronous multiplex system, one at the transmitting station and one at the receiving station. Suppose there are as many teeth as characters, there being one character on the face of each tooth. In circuit with the magnet controlling these wheels is a key, the pressing down of which will not only stop the rotation of each wheel, but will also cause an electromagnet to press the tape upon which the characters are to be printed against the tooth that stops opposite it. When the two wheels start to rotate, similar letters upon the two wheels must occupy exactly similar positions; that is, if the letter A is opposite a certain point at the transmitting station, the letter A must be opposite a similar point at the receiving station. Then, if the operator is able to momentarily stop the wheel at his station when the letter he wishes to transmit comes into a certain position, that same letter will be opposite the tape in the receiving machine, and the tape being pressed against it when the wheel momentarily stops, the character will be printed. When the key is released, the wheels will immediately start to rotate again and the paper tape will also be moved along by clockwork or otherwise. In this way any character can be printed in succession at the will of the transmitting operator.

217. A number of receiving stations may be connected in series in the same line circuit. It is necessary to make all the wheels rotate synchronously, which would not be an easy matter merely with clockwork. To obtain the synchronous rotation of the type wheels, usually a step-by-step mechanism, controlled by the transmitting apparatus, is used. This may be done by sending into the line one brief current every time each character of the transmitting wheel passes a certain point, each one of these brief currents causing a properly arranged electromagnet in the receiving instruments either to release a clock-driven wheel one tooth at a time or to actually push the wheel around one tooth each time. Furthermore, it is usually necessary to have a correcting device that will bring all receiving wheels absolutely to the starting point, no matter what their position may be at the instant the correcting device operates. It may operate about every third revolution of the receiving wheels.

STOCK-TICKER SYSTEMS.

218. Stock-ticker telegraphs may be divided into the *single-wire single-wheel*, the *single-wire double-wheel*, and the *two-wire double-wheel systems.*

In the **single-wire single-wheel** system, there is only one line wire, and all the characters, both letters and figures, are placed in succession on the periphery of one printing wheel. While this is theoretically the simplest method, it is not as fast as the others, and is not used as extensively.

In the **single-wire double-wheel** system, there is one line wire and two printing wheels alongside each other, one usually for letters and another for figures and other characters. The two wheels usually rotate together, but the paper tape is pressed up against only one at a time.

In the **two-wire double-wheel** system, there are two line wires and two printing wheels. The two printing wheels are alongside each other and have the characters on

their periphery, as in the preceding system, but in this case a separate wire is used to merely shift a pad from one to the other type wheel as required. One wire governs the rotation of the printing wheels and causes the pad to be pressed against the type wheel opposite which an electromagnet connected in the other line wire has moved it.

PAGE-PRINTING TELEGRAPH SYSTEMS.

219. There are two page-printing telegraph systems now receiving attention that use a perforated transmitting tape: the Murray page-printing telegraph and that of Mr. C. L. Buckingham. The received record in the Buckingham printer is made on the ordinary telegraph blank, resembling the Murray printer in this respect. The Buckingham system, which has recently come into commercial use on some lines of the Western Union Telegraph Company, has a maximum speed of about 100 words a minute on the circuit between New York and Chicago. The circuit can be duplexed, giving about double the above capacity.

MURRAY PAGE-PRINTING TELEGRAPH.

TRANSMITTING ARRANGEMENT.

220. Mr. Murray uses a special alphabet, perforating the transmitting tape with a keyboard perforator, having a separate movable lever for each character. Each character occupies an unvarying linear space on the tape, and consists of five perforated and unperforated subdivisions of such space. The difference in the number and succession of these subdivisions or perforations imparts the designating characteristics. There are no spaces between successive letters or characters. Either makes and breaks or reversals can be used in transmitting. It is to this fundamental fact—

letters of the same length—that the success of the ...m is due. Each letter occupies half an inch on the

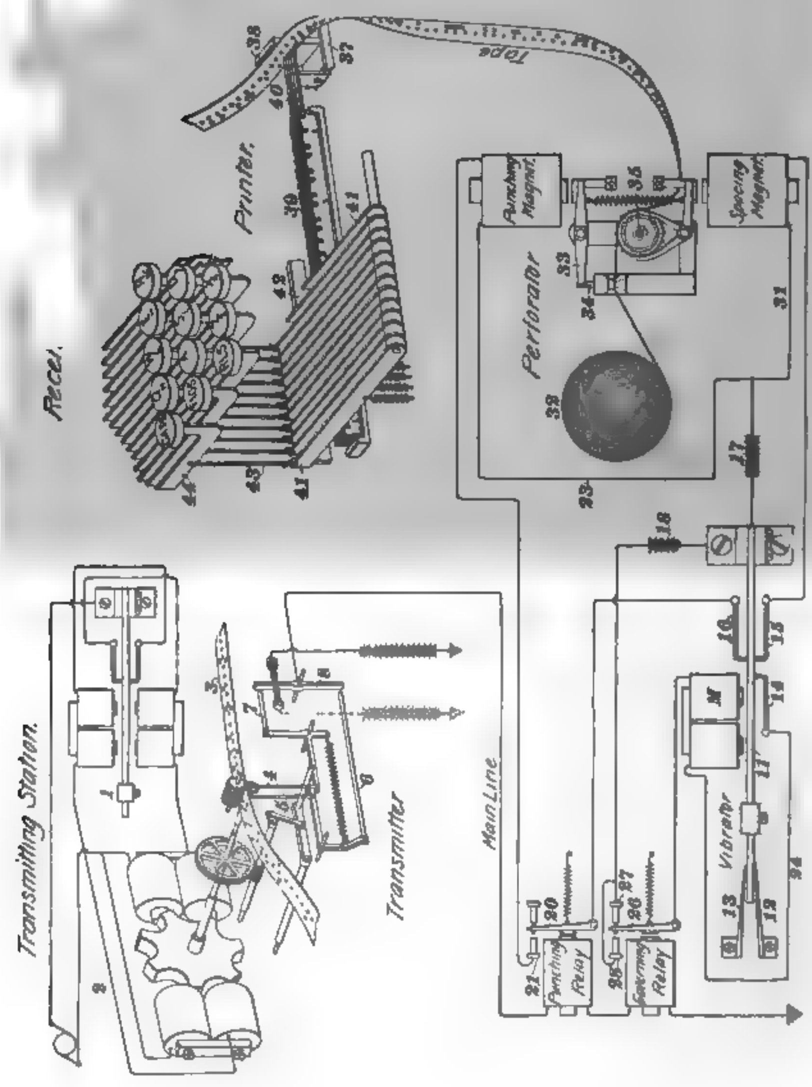


FIG. 74.

transmitting tape, and a similar length on the receiving tape. The result is that a comparatively simple transmitting-tape

perforator worked by an ordinary typewriter keyboard is rendered possible. In connection with the ordinary typewriter keyboard, there is a group of ten punches, one punching magnet, and one spacing magnet that controls a motor-driven escapement.

NOTE.—This description of the Murray page-printing telegraph is an abstract of a paper presented by Mr. W. B. Vansize to the American Institute of Electrical Engineers in January, 1901.

221. Receiving Apparatus.—At the receiving station there is an electromagnetic perforating device that accurately reproduces the transmitting tape by producing corresponding perforations and spaces. This receiving perforated tape passes from the receiving perforator into the typewriter-operating device. This typewriter-operating device consists of five longitudinally reciprocating bars or combs *39*, Fig. 74, presenting five pointed terminals *40*, to a perforated plate or die *38*. The perforated tape passes between the surface of the perforated plate and the pointed terminals of the bars. The pointed terminals of these bars register respectively with the five holes in the die. The tape is moved along between the die and the pointed ends of the bars step by step, the length of a letter or character at each step being, say, $\frac{1}{8}$ inch. When perforations in the tape coincide with the pointed ends of the bars and corresponding perforations in the plate or die, and the plate is moved toward the pointed ends of the bars, the bars may be separated into two groups: one group is moved longitudinally, corresponding with the unperforated subdivisions of the tape; the other group projects through the perforations in the tape and in the die and is unmoved. Lying over the five bars or combs at right angles thereto are a series of thin metal strips *41*; each strip is mechanically connected with its individual key lever on the typewriter. The upper surface of the five bars first described are notched arbitrarily. These notches are caused to be alined below any one of the strips under the control of the perforated tape and die; when any one of the strips drops into a groove, a motor-driven cam engages it and produces a movement of the

typewriter lever. The movement of the die and paper tape and of the typewriter-key lever is produced by motor-driven cams. It will be seen that this mechanism will operate not only a typewriter, but any keyboard machine, such as a typesetting machine or linotype. The perforated receiving tape is, therefore, available for setting type automatically.

222. The Diagram.—In the diagram shown in Fig. 74, the apparatus at the transmitting station is connected by a single main line with the apparatus at the receiving station. The vibrating reed *1* at the transmitting station is in a local circuit with an electromagnetic motor *2*. The reed makes and breaks its own circuit, and is substantially like the well-known La Cour phonic-wheel device used in the Delany and other multiplex systems. The "prickers" *4* and *5*, familiar features in the Wheatstone transmitter, are located as usual in line with the advancing lines of perforations in the transmitting tape *3*; *6* and *7* are reciprocating rods engaging respectively with opposite ends of the centrally pivoted pole-changing switch arm *8*. The parts shown are all essential parts of the well-known Wheatstone transmitter, which is here used practically without alteration, except that the prickers *4* and *5* are arranged to move or reciprocate *together instead of alternately*, thereby enabling any multiple of a single impulse to be transmitted. The ordinary arrangement of the Wheatstone transmitter can only transmit unit signals or odd-number multiples thereof; it can transmit a dot or a dash equal to three or five dots, but cannot transmit a dash equal to two or four dots. Mr. Murray, to avoid this difficulty, arranges the prickers to reciprocate together instead of alternately. There is thus obtainable transmitted impulses or dashes equal to one, two, three, four, or five dots, with corresponding spaces.

223. In transmitting, the number of impulses thrown upon the main line is minimized by producing the impulses locally at the receiving station and using only sufficient main-line impulses to determine the action of the perforator

at the receiving station. At the receiving station there is, therefore, a main-line relay to determine the action of the punching magnet, and a governing relay that operates to maintain unison between the main-line impulses as they arrive and the corresponding impulses in the local circuit. For the purpose of creating these local uniform impulses, there is a vibrating reed *11* (see Fig. 74), operated by an electromagnet *M*. The circuit of this magnet extends from the local battery *18* through the reed *11*, contact point *14*, wire *24*, magnet *M*, armature *26* of the governing relay, and thence by way of the points *27* or *28* to the battery. The precise operation of the governing relay will be described presently. The receiving perforator is composed of a punching magnet and a spacing magnet; the punching magnet operates a spring-retracted pivoted armature bar *33*, mechanically connected with the punch *34*, reciprocating through a guide block and engaging the tape upon the surface of a suitable die, over which the tape passes. The tape is fed along by a star wheel located on a motor-driven shaft *35*, and upon this shaft is an anchor escapement under control of the spacing magnet. The vibrating reed *11* alternately makes and breaks the local circuit of the spacing magnet; this circuit extends from battery *17* to the reed *11*, contact spring *15*, through the spacing magnet and wire *31* to the battery *17*. The punching magnet is in a local circuit with a contact point *16* operated by the vibrating reed *11* and controlled by the contact points of the punching relay, so that while the reed is continually generating local circuit impulses, these impulses are effective to operate the punching magnet at only such times as the punching relay is closed upon its front contact *21*. This local circuit passes from the battery *17* through reed *11* to contact point *16*, thence by armature *20*, contact *21*, through the punching magnet, and wire *23*, to the battery. It will thus be seen that the reed *11* is continually making and breaking two circuits alternately; first, that of the spacing magnet, which is a continuous operation; and second, that of the punching magnet, which is an intermittent operation, rendered so by

the action of the punching relay. This punching relay and also the governing relay may be either neutral relays responsive to makes and breaks or they may be polarized relays responsive to reversals of current; in only the latter case would the battery that is shown dotted at the transmitter be used. As the reed *11* vibrates, the electric impulses in the spacing-magnet circuit permit a steady progressive movement of the tape. Upon the arrival of an impulse of current from the transmitting station, the contact points *20* and *21* of the punching relay are held closed for one, two, three, four, or five times the time interval of one dot length; and while this relay circuit-breaker is closed, the punch *34* operates to perforate the tape as many times successively as permitted by the time length or duration of the transmitted impulse upon the main line Mr Murray has thus avoided the necessity of transmitting over the main line all impulses necessary to produce spacing, and all but a fractional part of the impulses necessary to produce the perforations. It is of vital importance, however, to preserve unison between the arriving transmitted impulses in the main line and the local punching and spacing impulses at the receiving station. This is done in the following manner.

HOW UNISON IS MAINTAINED.

224. The governing relay operates a circuit-breaker *26*, moving between two fixed contacts *27* and *28*, electrically connected to the same circuit terminal, so that the moving contact in going from one to the other operates to open the circuit during its time of transit only. This break in the local-vibrator circuit takes place at the beginning and end of each main-line signal, and as the main-line signals arrive at a uniform rate and are of unit or multiple-unit duration, the governing relay operates its break point at uniform unit intervals or multiples of these intervals. In the same circuit in which this break point operates, there is also the

break point *14* of the motor magnet *M*, which works on the familiar buzzer, or vibrating bell, principle. There are thus two break points in the same circuit. If they open and close together, then full vibratory impulses flow through the magnet *M*. If, on the other hand, the rate of vibration of the reed tends to accelerate, or the rate of the arriving current signals tends to lag, then the two breaks occur more or less alternately, and, consequently, less current gets through—the impulses are clipped—and the rate of vibration of the reed is reduced. In practice, the receiving vibrator is set to go 1 or 2 per cent. faster than the rate of the arriving signals, and then the governing action of the two interfering break points in the same circuit results in the establishment of a steady balance between the accelerating tendency of the reed and the retarding tendency of the arriving main-line signals. By this arrangement, the necessity for sending correcting impulses over the main line to secure synchronism is avoided, the correcting impulses being obtained locally with the co-operation of the main-line signals themselves.

It is to be understood that movable weights are present upon each reed, that of the transmitting station and that of the receiving station, and by varying the position of the weight upon the reed, the rate of vibration and the rate of transmission may be changed. It is necessary in maintaining unison to have a considerable range of variation in the speed of the reed at the receiving station, such variation in speed to be attained in response to variation in the length of current impulses of uniform strength.

225. Constrained Vibration of the Reed.—To secure this result there is placed at or near the free end and upon the opposite sides of the reed, resilient stops, shown at *12* and *13*. These springs receive the reed on each side with a cushioning effect and impart an initial return movement. In explanation of this result it should be stated that the rate of vibration of a reed varies with its length, mass, and the distribution of such mass; increase of

current in the magnet M circuit increases the amplitude of vibration without varying the speed beyond a practically negligible amount due to a slight electromagnetic damping effect. Rigid limiting stops have not proved satisfactory. By the use of resilient stops, the movement of the reed is rendered smooth and uniform; it is freed from the interference due to an impact with a rigid stop, which would act to jar and disturb the normal rate of vibration; and its rate may be varied by varying the length of the current impulses.

226. Shape of Punch.—The shape of the punch for perforating the receiving tape is quite important. The punch shown in Fig. 75 has the best shape.

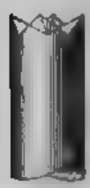


FIG. 75.

227. The Murray Alphabet.—Murray, by using multiple units of current and space (that is, by using several different time intervals instead of only one), has not found it necessary to use reversals. The Murray alphabet is shown in Fig. 76. It will be seen that the uniform time for each letter is divided into 5 equal units or subdivisions, one or more of these 5 subdivisions being a current impulse, so that we get current impulses or spaces of 1, 2, 3, 4, or 5 units duration. Thirty-two possible combinations are obtained in this manner, and by using two of these letter signals as prefixes to the others for capitals, figures, and lower-case letters, about 87 characters may be transmitted. Makes and breaks or reversals may be used, therefore, adapting the system for use in quadruplex transmission, a use not practicable with an alphabet using both makes and breaks and reversals as in Baudot's alphabet. The alphabet, however, is only avaible for machine telegraphy, as it is practically impossible to observe five different time intervals with sufficient accuracy in manual transmission. No space is required between letters in the Murray alphabet, whereas in the Morse a 3-unit space follows each letter. It will be seen upon examination of Fig. 76, that the maximum number of impulses required is 3 for the letter y, and the average number reckoned according to the frequency of the

letters is 1.25 impulses per letter as against 2.59 for International Morse and 5 for the Baudot alphabet, in addition to the necessary correcting impulses to secure or maintain

TABLE OF ALPHABETS

	LETTERS	FREQUENCY	"MURRAY" SIGNALS	"MURRAY" TAPE	"BAUDOT" ALPHABET	"INTERNATIONAL" MORSE	"AMERICAN" MORSE
1	e	14,000		o····			
2	t	10,000		····o			
3	a	9,000		oo···			
4	i	9,000		·oo··			
5	n	8,000		··oo·			
6	o	8,000		···oo			
7	s	8,000		o·o··			
8	r	7,000		·o·o·			
9	h	6,000		··o·o			
10	d	5,000		o··o·			
11	l	5,000		·o··o			
12	u	4,500		ooo··			
13	c	4,000		·ooo·			
14	m	3,000		··ooo			
15	f	3,000		o·oo·			
16	w	2,500		oo··o			
17	y	2,500		o·o·o			
18	p	2,400		·oo·o			
19	b	2,000		o··oo			
20	g	2,000		·o·oo			
21	v	1,500		·oooo			
22	k	800		oooo·			
23	q	600		ooo·o			
24	j	500		oo·oo			
25	x	500		o·ooo			
26	z	300		ooooo			
27	,	4,500		o···o			
28	.	3,000		oo·o·			
29	Space Key			··o··			
30	Capital Key			·o···			
31	Figure Key			···o·			
32	Release Key			·····			

BAUDOT
1 – É
2 – "ERROR"
3 – NOT USED

FIG. 76.

synchronism. Murray has the shortest alphabet possible to be constructed from reliable signaling material, and by combining it with machine transmission, the entire time of the line is used in the most advantageous manner possible.

COMPARISON OF ALPHABETS.

228. Referring to Fig 77, it will be seen that the Murray word is shorter than the Morse in the ratio of 30 to 51, or 41.18 per cent This is borne out by a comparison made with an actual word, such as Paris. This comparison is made on lines *13* and *14*. It will be observed that in this case the Murray alphabet is shorter than the Morse in the ratio of 30 to 49, or 38 78 per cent. Practically, the two alphabets are in the ratio of 3 to 5 Hence, using the same number and length of current impulses in each case, a speed

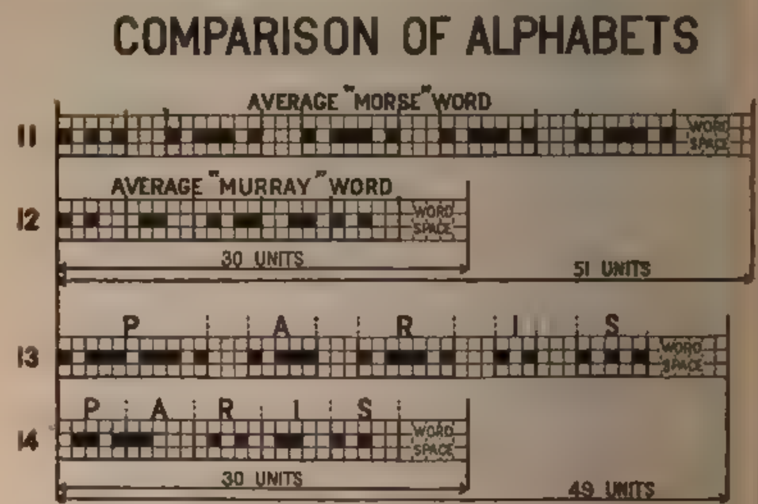


FIG 77

of 100 words a minute with the Murray alphabet would not be more than about 60 words a minute in Morse The saving in the Murray alphabet lies chiefly in the fact that there is no space between the letters. Indeed, signals in adjoining letters not unfrequently coalesce, as will be seen in the case of the letters p and a in the word Paris, where one current impulse is actually shared by the two letters, and five letters are transmitted by 7 impulses, whereas in the Morse representation of the same word no less than 14 impulses are required

TESTS OF THE SYSTEM.

229. Speed.—From time to time, as the system developed, careful tests were made of its capacity, both on loops of varying lengths and on circuits between cities. The speeds mentioned below were calculated on the basis of 5 letters to the word and a word space equal to 1 letter. That is to say, the receiving tape fed through the perforator in 1 minute was measured to find the number of letters it contained, and this number was divided by 6. In April and May, 1900, a series of tests were made between New York and Chicago. Working direct from Chicago to New York via Meadville without a repeater, a distance of 1,050 miles by the route of the wire, the best speed attained was 77 words a minute. Working with a repeater at Meadville, much better results were achieved, 102 words a minute being easily attained. The wire used was copper, 208 pounds and 4.5 ohms per mile. Duplex working was readily secured. Attempts were made to reach a speed of 114 words a minute. These were only partially successful, but the results gave promise of a speed of at least 120 words a minute in the future.

The most exhaustive tests of the system were made from October 17 to November 3, 1900, between Boston and New York. Two hundred ordinary commercial messages were transmitted, consisting of 160 business telegrams (including 18 in cipher) and 40 domestic and social. They averaged 10.8 words in the paid portion of each message. Following the usual practice of counting single figures as words, they averaged about the usual rate of 30 words per message; but, counting figures as single letters, and counting all letters by measuring the transmitting tape and dividing by 6, the average was about 26 words per message. These 200 messages were perforated in Wheatstone tape. A column press despatch from the New York "Herald," containing 5,988 letters and 1,261 words, or an average of 4.75 letters per word, was also prepared in Wheatstone tape. This press despatch and the 200 commercial messages were transmitted from Boston to New York day after day at speeds

varying from 60 to 96 words per minute. It was found that the apparatus worked with great accuracy, the whole 200 messages frequently coming through without error. At other times occasional errors occurred, owing to swinging wires and other familiar line troubles common to all telegraph systems.

230. In regard to the number of messages transmitted per hour, in tests made when the apparatus was running at 61 words per minute, the 200 messages came through to New York in 1 hour 23 minutes. This is a speed of about 144 messages per hour, or more than three times the average rate of transmission by the Morse key, 40 messages per hour being regarded as a fair day's work for an average operator. At the 96-word rate the messages came through at about 230 per hour.

The length of the Postal Telegraph Company's lines from New York to Boston is about 290 miles, and the lines include from 20 to 30 miles of cable. Over this comparatively short line the system did not require any readjustment for weather, which varied during the tests from clear and cold to dense fog and rain all the way between the two cities. Duplex working was perfect.

231. It will be seen from the foregoing tests that this system, working at the 60-word rate, has a capacity of 140 messages per hour. Cutting this down to 120 messages per hour to allow for corrections and delays, and working duplex, there is an output of 240 messages per hour, or 50 per cent. more than the Morse quadruplex can achieve.

The tests have shown that, owing to the characteristic alphabet, distances of 1,000 miles are not an obstacle, and the inventor is sanguine enough to believe that it will be possible, though not at present commercially practicable, to work between New York and San Francisco, a distance of 3,000 miles, at a speed of at least 40 words a minute, or double the rate of manual transmission.

AUTOMATIC FACSIMILE TELEGRAPH SYSTEMS.

232. The **facsimile telegraph system** is one that transmits the facsimile of a drawing or writing that has been previously prepared upon a flat or smooth surface. The methods usually employed involve a synchronous rotation of two metallic cylinders, one at the transmitting end and the other at the receiving end.

HUMMELL FACSIMILE TELEGRAPH.

233. In 1898 the New York "Herald" experimented with the **Hummell** system of picture telegraphy, and since then the same journal has been making experiments with an improved form of the Hummell apparatus in connection with the Chicago "Times-Herald," St. Louis "Republic," Philadelphia "Inquirer," and Boston "Herald."

234. The apparatus, as described in the "Telegraph Age," consists of a receiver and transmitter, which are similar in appearance and mechanism. The picture to be transmitted is drawn on a heavy piece of metal foil, the lines of the drawing being made with an insulating ink. The foil is then secured on the circumference of a horizontal cylinder on the transmitter, the cylinder being about the size of a typewriter rubber roller. There is a similar cylinder on the receiver, upon whose surface is clamped the paper on which the drawing is to be produced; over this is superposed carbon paper, which is covered in turn by a sheet of thin paper. A style actuated by an electromagnet is adjusted close to the surface of the latter, and each time a current is passed through the electromagnet the style is forcibly pressed against the moving surface of the cylinder and a corresponding mark is made on the two sheets in contact with the carbon paper; the outer sheet serves merely to form a smooth surface for the style and to enable

the operator to see that the picture is being properly produced.

235. The transmitting cylinder passes under a similar style that closes the circuit between the receiving and transmitting ends when it rests upon the foil, and opens the circuit when it passes over the lines drawn with insulating ink, in the latter case causing the style magnet at the receiving end to leave a mark on the paper on the receiving cylinder in the form of a line corresponding to the width of the insulation over which the transmitting style passes. The style at each station is simultaneously advanced at the end of each revolution of the cylinders by a screw of small pitch. If the surface of the foil on the transmitting cylinder were entirely insulated, the receiving style would merely draw a number of parallel lines on the paper corresponding to the turns of the screw, and separated a distance corresponding to the pitch of the screw and the angle through which it is turned at each operation. Four different rates of advance may be given the style, corresponding to as many different angles of advance that may, by appropriate mechanism, be given the screw.

236. The two cylinders have synchronous motion, so that all the marks or lines on the receiving cylinder correspond to widths of insulating ink marks on the transmitting cylinder. Synchronism is obtained as follows: Connected with both receiver and transmitter is an electric motor that, at the end of every revolution of the cylinder, raises a weight that acts upon a clock train when falling and thus gives motion to the cylinder. At the end of each revolution of the transmitting cylinder, a contact is made that locks for an instant the receiving cylinder when it arrives in a position corresponding to a similar position of the transmitting cylinder. Thus it will be seen that each cylinder begins its revolution from identical positions and at the same instant, and as the clockwork of both receiver and transmitter are duplicates, approximate synchronism is maintained during a revolution. Owing to the use of carbon

paper, the lines made by the receiver are of considerable width, and in consequence the resulting picture has but slightly the appearance of being made up of parallel lines.

237. The Hummell apparatus appears to be entirely practicable, and its synchronizing mechanism is quite simple. The apparatus has been worked duplex with success. In one instance, a picture was sent from New York to St. Louis, while one sent from St. Louis was being received in New York, the latter picture, in addition, being received simultaneously at Boston.

DUN LANY FACSIMILE TELEGRAPH.

238. The International Facsimilegraph Company, in which the managers of the Associated Press take an interest, have been developing the facsimile telegraph system patented on August 22, 1899, by P. Dun Lany and Thomas Mills. In transmitting a picture or drawing by this system, it is first stereotyped on a flexible metal plate. The outlines of the picture are exposed, while the remainder of the surface of the plate is covered with a non-conducting paint. The plate is then placed around a brass cylinder 5 inches long and 2 inches in diameter, and the machine, which is operated by an electric motor, is started. An arm bearing a tracer has its base upon a very finely threaded rod. The arm is gradually moved to the left, until the entire picture has been covered by the tracer. Both sending and receiving machines are governed by a simple synchronizing arrangement, so that both machines are automatically regulated in their speed and run exactly together. The tracer at the sending point controls the current on the wire and closes the circuit whenever it comes in contact with the exposed lines of the picture.

239. At the receiving end, the apparatus is similar to that at the transmitting point. The arm projecting over the cylinder, however, is provided with a style controlled

by an ordinary telegraph sounder. Around the cylinder is wrapped several sheets of paper having carbon copying sheets between them. The sounder operating the style causes the latter to bear down upon the cylinder and copying paper, recording the most minute lines in the original picture as the tracer at the sending point passes over them. A portrait was successfully transmitted by this method over a 650-mile circuit between Cleveland and St. Louis.

240. In transmitting written or printed matter, the process is the same, except that the copy is either written or copied on a flexible metal plate, the circuit being broken whenever the tracer strikes the non-conducting ink. In this case the receiving instrument is reversed, so that it records on the paper the opening instead of the closing of the circuit. The synchronizing arrangement is very ingenious. It is said that the operator at the transmitting point, no matter how many receiving machines there may be cut in along the line, can easily correct or regulate the speed of all.

It is claimed that by using an enlarged cylinder, a half or even a full newspaper page, in matrix form, can be placed in a transmitting machine, operated, say, in New York or Chicago, and reproduced simultaneously in practically all the leading cities of the country within a very few minutes.

AMERICAN DISTRICT TELEGRAPH SERVICE.

241. In all large cities there are companies with some such title as in the above heading that enable a subscriber to notify them that a messenger, hack, policeman, fireman, doctor, or some other service is desired at once. The subscriber, by turning the crank on a small *call box* placed in his office, causes a certain special signal or number to be sent to the central office, thereby notifying the central

office exactly what subscriber is calling. The majority of call boxes in use are of this type and are used merely to call for a messenger. However, call boxes are also used that enable the subscriber to notify the central office whether a messenger, doctor, policeman, fire department, or other service is desired. Furthermore, all types of call boxes may be fitted with a return signal whereby the subscriber is notified by the ringing of a bell or by some other signal that his call has been properly received. Lately the telephone is being adapted by some district telegraph companies. A telephone specially connected is installed in each subscriber's office to enable the subscriber to call up the central office and make his wants known. However, the central office cannot usually call up the subscriber nor can one subscriber be furnished with connection to any other subscriber. In other words, there is no provision or intention whatever to enter the telephone-exchange business.

242. Call boxes are made in an almost infinite number of different ways and for various purposes. However, they are invariably connected in series in a circuit that does not normally use the ground as a return conductor. Morse ink or embossing registers are invariably used at the central office to record the calls sent in by the subscribers, and, in addition, a bell or gong is generally used to notify the central-office attendant that a call is coming in.

243. A diagram of connections used in the district telegraph service is shown in Fig. 78, in which the central office and four subscribers' call boxes *A*, *B*, *C*, and *D* are included. At the central office, the line circuit normally includes the key *k*, battery *B*, and relay *R*. If call box No. 42 is properly operated, the line circuit, which is normally closed, will be opened 4 times, and after a proper interval 2 times, thus causing the armature of the relay to close, on its back stop, a circuit containing a local battery *L B*, a Morse ink or embossing register *E*, and a gong *S* 4 and 2 times. Thus a record of the signal 42 is made on the register *E* and at the same time an audible signal is

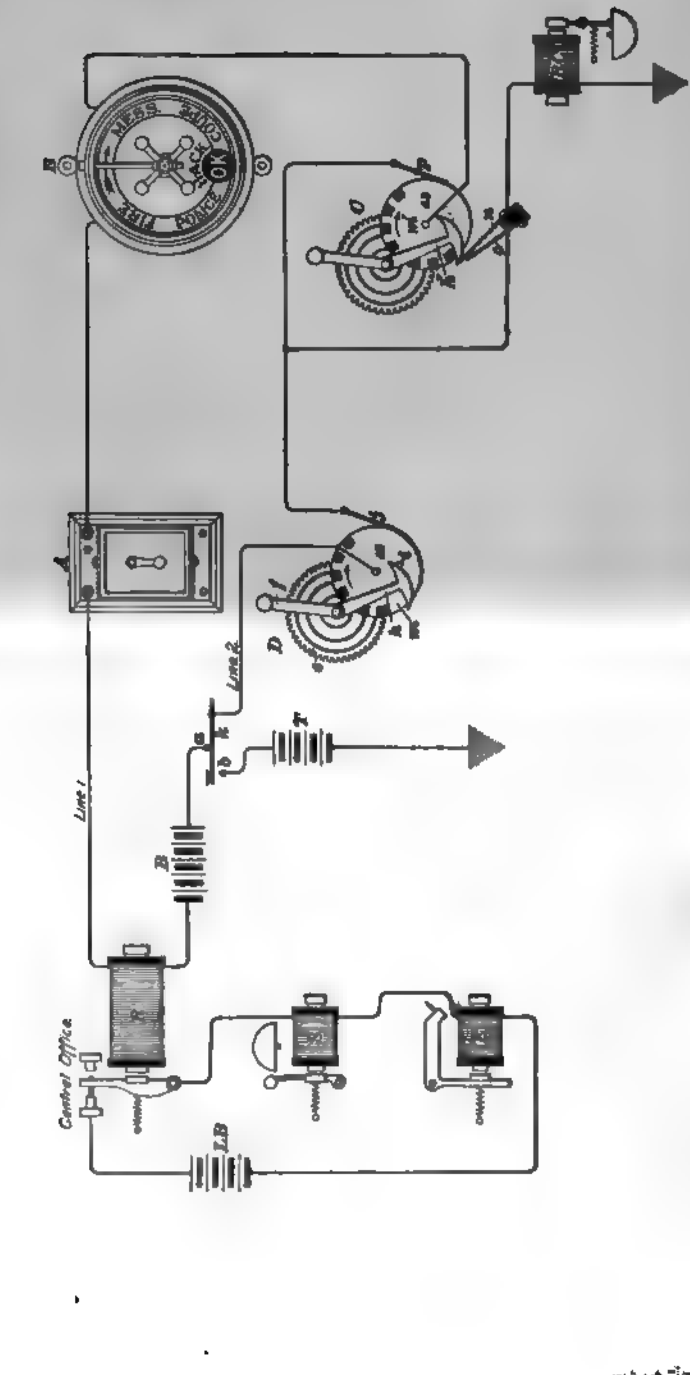

MESS
COURSE
BACK
OK
FIRE
POLICE
Line 1
Line 2
D
B
T
LB
Central Office

FIG. 12.

made by means of the single-stroke gong or bell *S*. If return-call boxes are used on this circuit at the subscribers' station, the attendant presses the key *k* immediately after receiving the signal, thus sending a current from the return-call battery *T* over the line to the box that has been operated, where a momentary connection to earth affords a return circuit. The batteries *L B* and *T* usually consist of Leclanché cells, and *B* of some form of closed-circuit cells, such as gravity, Gordon, Edison-Lalande, or storage cells, or a converter or motor dynamo may be used. *A* and *D* represent ordinary single-call boxes, *B* and *C* return-signal boxes, *B*, as indicated, having five distinct calls.

244. The mechanism at *D* consists of a gear-wheel *e*, having a spiral spring that is wound up whenever the crank *f* is turned in the act of calling for a messenger. When the crank is released, it returns to its normal position. When the handle *f* is turned, the stop *h* moves out of the path of the pin *i* and the spring propels the mechanism, causing the break wheel *m* to make 1 revolution in the direction of the arrow; the lever *h* coming in the path of the pin *i* stops the wheel at exactly the same place every time. As the wheel revolves, the circuit between the wheel and the brush *j* is broken every time an insulated segment on the periphery of the wheel comes under the brush. Thus at station *D*, the circuit is broken 4 times, and then 2 times, causing the signal 42 to be sent into the central office.

245. Multiple-Call Box.—In a call box such as shown at *B*, by means of which several different calls may be made, the circuit would be interrupted, after the box number would have been sent in, once for a messenger, twice for a coupe, three times for a hack, etc. Upon the periphery of the break wheel there would be, besides those necessary for sending in the box number, such additional insulated segments as are required for the various calls.

246. Return-Call Box.—At *C* in the figure is shown the mechanism of a return-call box. It has two springs *o*

and *n* that are normally insulated from each other, and also from the break wheel *m'*. The break wheel when released makes 2 complete revolutions. Upon making the second revolution, the arm *h'* comes into such a position as to press the two springs *n* and *o* together, for a short time only, however. If, while these two springs are in contact, the attendant depresses the key *k*, a current from the return-call battery *T* will pass out over line *2*, through the springs *o* and *n* and the magnet *R C* of the return-call bell, and returns through the ground. It is necessary with this type of box for the attendant to depress the return-call key as soon as the whole signal is received, otherwise he cannot give the return signal. Return-call boxes may be manual or automatic. In one form of the manual return-call box, the subscriber, after calling, must press his finger on a knob, or push button, in order that the office may signal back. This is done by causing a little ball to tap against a glass disk, thus informing the subscriber that his call has been received.

247. Automatic Return-Call Boxes.—Box *B* in this figure is an automatic return-call signal box made by the Viaduct Manufacturing Company. When the subscriber calls, the O K disappears and when the office signals back, the O K drops into view, signifying that the call has been received. The return-call magnet has a resistance of about 13 ohms and the normal current due to the battery *B* is not sufficient to operate it.

248. The **Field and Fireman** return-call box made by the Western Electric Company has provision for sending in as many as 11 different calls. When primary batteries are used with this call box, the arrangement is generally as shown in Fig. 79. At *C* enough of the box mechanism is shown to enable the student to understand the method of giving the return signal. Normally, the gravity battery *B*, containing about 14 cells, sends enough current through the circuit to keep the relay energized; and the magnet *Rs*,

which gives the return signal, is short-circuited by the connection between the spring *b* and the piece *a*. When a call is made by moving the lever *f*, the piece *a* is moved so that

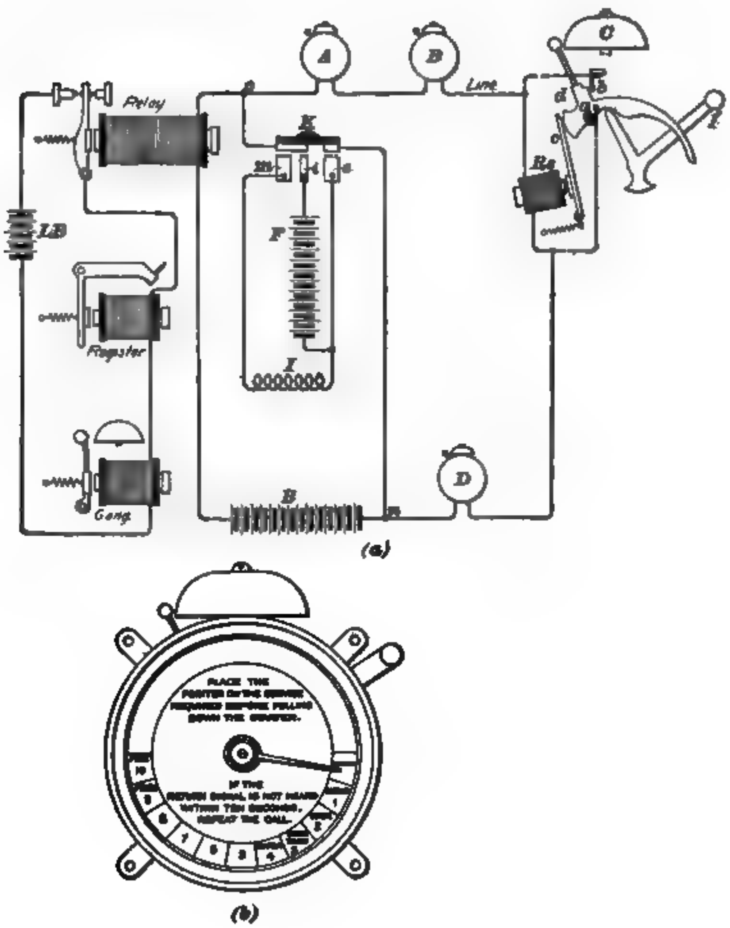


Fig. 73.

the spring *b* is separated from *a*, thus opening the short circuit around *Rs*, and, furthermore, the hook *c* catches at *d* and holds the circuit open between *a* and *b*. The magnet *Rs* is then directly in the line circuit. While the box is in this

condition, just after a call has been completed, the attendant presses a special push-button key *K*, which connects *e* to the line at *n*, and *i* to the other line at *o*. This connects the battery *F* of about 12 Leclanché cells and the large spark coil *I* between *n* and *o*. On account of the high inductance of the coil *I*, almost all of the rapidly increasing initial current from *F* will pass over the line, momentarily energize the return-signal magnet *Rs*, cause its armature to release *a*, the hammer attached to which strikes the gong, and the circuit around *Rs* is closed at *b*. The current is only on a moment while the key *K* is depressed.

249. Many boxes have a provision for temporarily or permanently grounding the circuit in case of a break somewhere in the circuit. By also grounding both sides at the central office, all boxes are still in working condition, but with a ground return, instead of a complete metallic circuit. With metallic circuits, which are the ones generally used, one accidental ground on a circuit does not interfere with the operation of the system. In the case of two grounds on the same circuit, only the call boxes between the two grounds are rendered useless until one or both grounds are removed. It is customary to make regular tests at the central office of every call box about once an hour, in order that grounds and breaks may be detected and removed. It is further customary to have extra relays at the central office that may be instantly cut in the circuit in place of the regular relays, in case any of the latter fail to work. All possible precautions are taken to keep all circuits always in working order.

Switchboards resembling those in telegraph offices are used for connecting the central-office relays, batteries, and test instruments with the various circuits. Although as many as 100 call boxes may be operated in one circuit, it is not customary to connect over 50 in the same circuit. With such a large number there is so much more danger of signals from more than one box being sent in at the same time. In district telegraph systems, usually no provision is made to avoid the interference of one signal with another.

In case it happens and the attendant is unable to recognize one or both signals, there is no remedy, and one or both subscribers must repeat their calls. In case the subscriber has a return-call box, he will know from the absence of a return signal, that he should repeat his call.

M'CULLOH DISTRICT TELEGRAPH SYSTEM.

250. Ordinarily, a break in the line might result either in the cutting out of all call-box stations beyond the break or in making the entire circuit inoperative until the break is located and repaired. To avoid this defect, the arrangement shown in Fig. 80 was devised by Mr. C. F. McCulloh. The boxes have ground connections that are normally open, but the ground connections are closed temporarily when the boxes are operated, and the ground at the central office may be connected to the circuit at any time by the attendant. The boxes are provided with a device for simultaneously making and breaking connections with the main line and with the ground, so that while the line is intact, the current returns over the line wire, but in the event of a break, the return is through the ground. Nothing short of two simultaneous breaks, one on each side of the station, can throw a box out of communication with the central office and even then the other stations on the same circuit are not affected.

251. Operation. — Ordinarily, common pin plugs would be placed in the holes *a*, *b*, *c*, and *d*, and the switches s_1 and s_2 would be turned to the left so as to connect with the two grounded buttons e_1 and e_2, as shown here for the call-box circuit No. 1 (*C. B. C.*, *No. 1*). The current may be traced from G_1, through e_1, s_1, R_1, *t*, *b*, *u*, call-box circuit No. 1, *v*, *a*, *w*, B_1, *G*, and finally back to G_1. This is shown in the small detached diagram (*z*), which is lettered the same as the other part of the figure. The central office is immediately notified if a break occurs on a circuit, because the

current through the relay in that circuit will cease and hence the gong will ring once.

In case there is a break somewhere, as at y on the No. 2 circuit, the switch s_2 should be turned to the right in contact

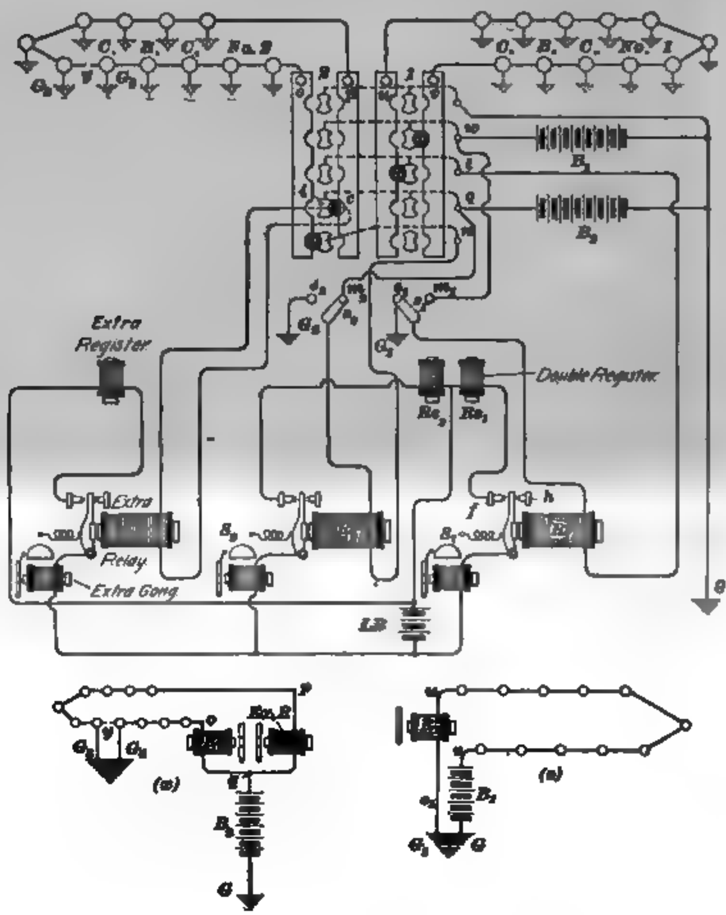


FIG. 60.

with the button m_2. A split wedge, containing the extra relay in circuit with it, should be inserted in the hole c, as indicated. This will make two outgoing parallel circuits

worked with the same battery B_2 and a ground return whenever a call box on this circuit is operated. This is clearly shown in the detached small diagram (x), in which the circuit is lettered the same as in the other part of the figure. One circuit may be traced from the battery B_2 through q, i, extra relay, c, p, call-box circuit No. 2, to a ground, as at G_3, at some box from which a signal is being sent and back through the ground to G and the battery B_2. The other circuit from the battery B_2 passes through q, m_2, s_2, R_2, n, d, o, call-box circuit No. 2, to a ground, as at G_4, at some box from which a signal is being sent and back through the ground to G and the battery B_2. Thus stations on both sides of the break can signal the central office.

252. Breaks and Grounds on Line.—The central office is notified immediately a break or ground occurs on an otherwise good circuit. For, suppose a break occurs on circuit No. 1, and that the wire on the side of the break connected to v becomes grounded. When the break occurs, all current will be cut from the relay R_1, the gong S_1 will sound, and the register Rs_1 start. The attendant recognizes that the one side is open and can test to determine whether the other side is grounded or open by inserting in the hole a a split wedge, containing in circuit with it an extra relay.

If the No. 1 circuit is grounded on the v side of the open circuit, the extra relay will be energized; if open, it will not be energized. If the side connected to u [see diagram (z)] becomes grounded and the other side opens, there will be no current in either R_1 or in the extra relay, because now no current flows from B_1 in either side of the No. 1 circuit. In this case, the register Rs_1 and the extra register will run until stopped. In case of an open circuit and the registers start, the local circuit should be transferred from the back stop f to the front stop h of the relay to stop the register and also in order that the gong will sound when the break is repaired and the relay is again energized.

253. Double-pen ink registers are commonly used in district telegraph offices. The one local battery $L B$

supplies current for the three local circuits. A good form of open-circuit cell, storage batteries, or converters may be used at *L B*. B_1 and B_2 should be closed-circuit cells, storage batteries, or converters. Whenever storage batteries or generators are used, resistances and fuses to limit the current to a safe strength should be connected in each circuit.

M'CULLOH SYSTEM WITH DYNAMOS.

254. The connections of the McCulloh system, as used in Denver, where dynamos are used, replacing 175 gravity and Leclanché cells, is shown in Fig. 81 (*a*). The momentary grounding of each call box when operated made it necessary to place the 400-ohm relay that controls the register recording the call on the same end of the circuit with the generator. On this account the arrangement shown here was made to enable the operator to at once detect a ground, heavy escape, or break in the circuit. There is a 400-ohm relay that controls the register on the dynamo end and a 150-ohm relay that controls a vibrating bell on the ground end of each circuit. Both the register and vibrating bell are normally connected to the back contact stops of their respective relays, enough current being used to keep both the relays closed. However, the local contact stops of the relays are so connected that either the front or back stop may readily be used as the occasion demands.

255. There are fourteen circuits in the Denver system; the current for all of them is supplied by a motor dynamo giving 24 volts, the positive brush being connected toward the line. The current is reduced by means of resistance lamps to such a strength that it will not magnetize the 13-ohm coil of the answer-back signal magnet in the subscriber's box sufficiently to cause the O K sign (see *B*, Fig. 78) to drop into view.

The answer-back push button when pressed down grounds the end of the circuit just outside of the 150-ohm relay, and at the same time connects 170 volts positive to the other

end of the line just outside the 400-ohm relay. Enough current is thus forced through the circuit containing the

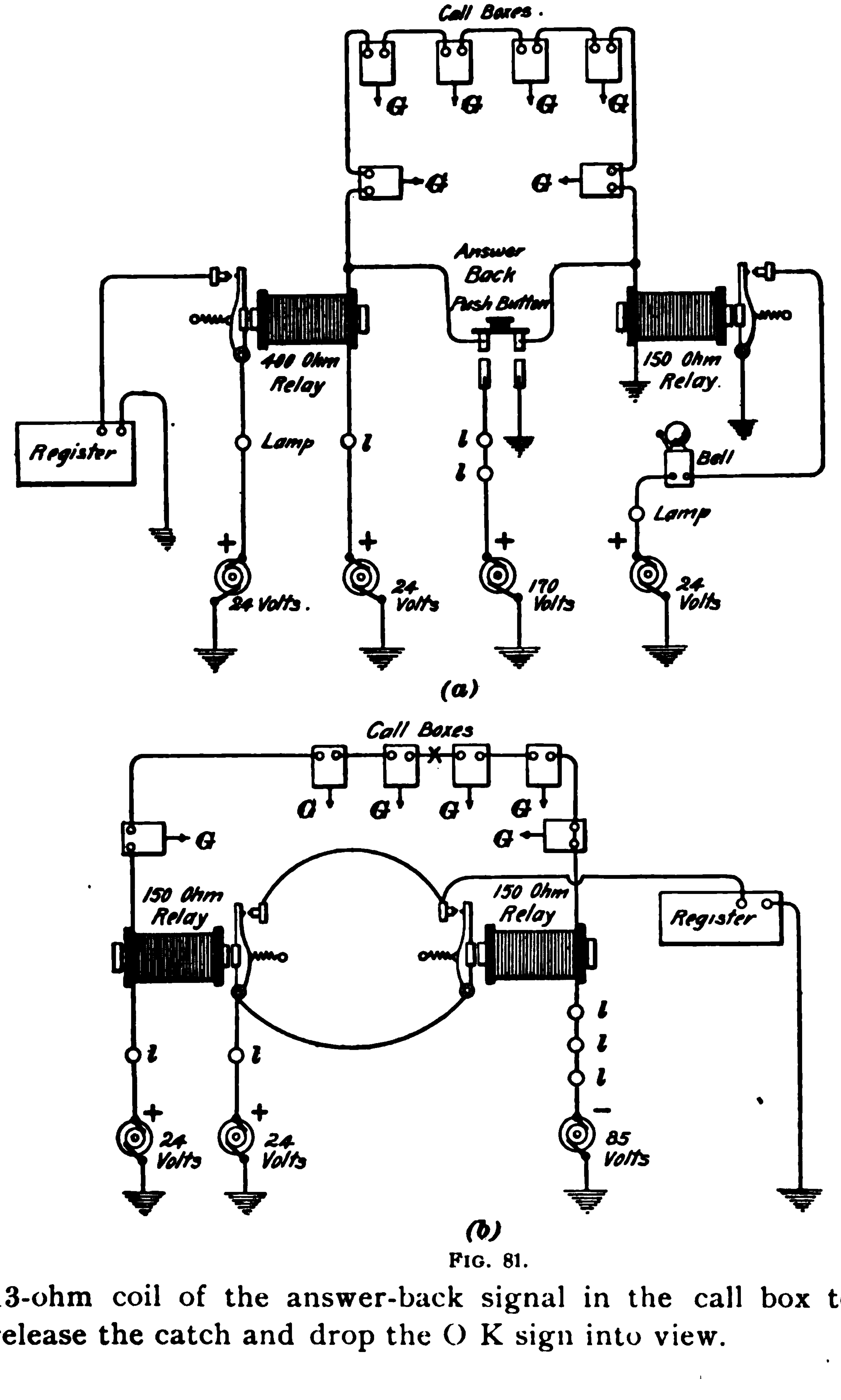
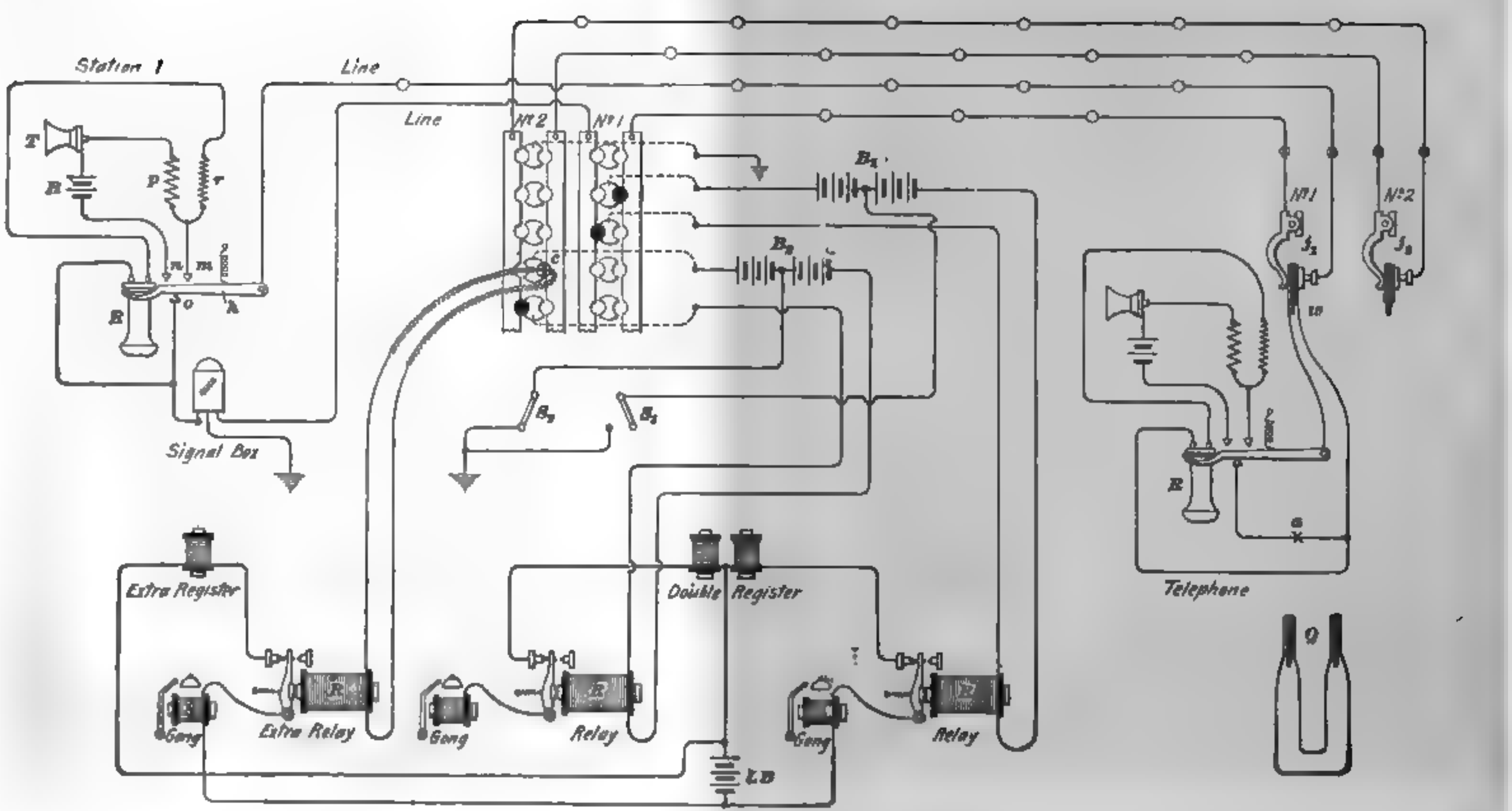


FIG. 81.

13-ohm coil of the answer-back signal in the call box to release the catch and drop the O K sign into view.



Station 1
Line
Line
T
R
p
r
E
Signal Box
No. 2
No. 1
B_1
B_2
S_2
S_1
No. 1
No. 2
J_1
J_2
Telephone
Extra Register
Extra Relay
Gong
Relay
Gong
Double Register
Relay
Gong
LB
Q

FIG. 88.

256. In case of a ground, escape, or opening of a circuit, the current being cut off from the 150-ohm relay causes the relay to open, thereby closing the local circuit and ringing the bell. The operator at once switches the circuit to a set of so-called McCulloh relays, as shown at (*b*), so that no call will be lost, unless more than one break or ground occurs at the same time on the same circuit. A break is represented in this figure by the cross on the line wire. One of the relays being connected to the 24-volt positive dynamo, the other had to be connected to the 85-volt negative dynamo, no smaller negative voltage being available, and opposite polarities being desirable, so that the two relays will close when a break on the circuit is repaired. The operation of either relay will work the register. The switchboard, which is a collection of small spring jacks, having 14 jacks for each circuit, was made expressly for these circuits, and is so wired that changes may be rapidly made from the regular relays to McCulloh sets, making it almost impossible for a call to be lost.

TELEPHONE IN DISTRICT TELEGRAPH SYSTEM.

257. The telephone is coming more and more into use every day in district telegraph, police, fire-alarm, and railroad systems. In Fig. 82 is shown an arrangement introduced by the Viaduct Manufacturing Company for the use of the telephone in the district-telegraph service. The circles in the line circuits represent subscribers' stations. The connections at one subscriber's station are shown in full at the left. Besides the usual strap switchboard, relays, registers, gongs, and batteries at the central office, there is also a spring jack in each loop circuit and a few telephones connected, as shown at the right side of the figure, to wedges or plugs *w*, and a number of plugs connected in pairs, as at *Q*. Normally, there is no wedge in the jack and the receiver *R* rests on the regular telephone hook switch. In this state of affairs any subscriber can call up the central office by turning the handle of an ordinary single-call signal

box in the usual manner. As soon as the call is received on the register in the No. 1 circuit, for instance, the operator inserts a double wedge *w*, to which a telephone is connected, into the jack j_1. Both subscriber and operator put their receivers to their ears and can then communicate with each other. The subscriber makes his wants known and the operator attends to them. When the receiver *R* is removed from the hook, the lever *h* makes contact with *m* and *n* and parts from *o*. This closes a local circuit containing the battery *B*, the telephone transmitter *T*, and the primary winding *p* of an induction coil. It also connects the receiver *R* and the secondary winding *r* of the induction coil in series in the line circuit.

258. No method is here shown by which the central office can call up a subscriber. If this is done, it requires either an answering battery and key of some kind at *a* and a gong at the signal box or a magneto generator at *a* and a magneto, or polarized, bell at the subscriber's station. It is not absolutely necessary or advisable in some cases to use a hook switch in the telephone at the central office. The telephone-transmitter circuit may be closed permanently during the busy part of the day and the receiver and secondary winding of the induction coil permanently connected to the two sides of the wedge *w*. Plugs, connected together as at *Q*, may be used, by inserting each in a different jack, to interchange the grouping of the call-box circuits. A simple telephone switchboard could be used in place of the jacks and plug circuits shown here.

259. Signaling in Case of a Fault.—Suppose there is an open circuit, or ground, at some point on the No. 2 circuit. By turning the switch S_1 to the left and inserting a split plug, connected to an extra relay, in the switchboard at *c*, subscribers on both sides of the trouble can still signal the exchange. This will put half the battery B_2 and a relay in circuit with each portion of the circuit. A signaling box, such as that made by the Viaduct Manufacturing Company, which makes connection alternately with one line and the

ground when operated, must be used at each station. B_1 and B_2 are main-line closed-circuit batteries; all the other batteries usually consist of Leclanché cells. When this arrangement is equipped to send in fire-alarms, a so-called *slow-motion fire-alarm box* will be used. The mechanism of such a box is constructed so that the signals follow one another slowly, thus allowing the gongs to strike slowly. Fire-alarm boxes usually repeat the number of the box three to five times.

260. The American District Telegraph Company in New York City has introduced on some of its circuits a compact signal and telephone instrument. The telephones are worked upon a common-battery system, there being no battery for the telephone transmitter at the subscriber's station, all batteries being located at the central office. On each box are two push buttons, one on each side of the instrument for connecting either side of the line to the ground. By pushing one or the other of these buttons in case of an open circuit on the loop, communication may still be maintained with the central office.

TESTING.

ROUGH TESTS.

261. The testing of circuits and apparatus is an important matter in all branches of electrical work. The general methods described in *Electrical Measurements* are, as a rule, directly applicable to telegraph work, but more specific directions will be given here. In testing either lines or apparatus, it is frequently necessary to make rough tests to show whether or not circuits are continuous or broken, or whether they are crossed, grounded, or properly insulated. These tests do not require accurate measurement, they being merely for the purpose of determining the existence of a certain condition without the necessity for measuring accurately the extent to which that condition exists.

MAGNETO TESTING SET.

262. A very common and useful form of testing instrument is that consisting of a magneto generator and polarized bell, together with some simple form of telephone, all mounted compactly in a box provided with a strap for convenience in carrying. Such an outfit is shown in Fig. 83. The polarized bell is usually connected in series with the generator, which is preferably provided with an automatic shunt. The circuits of a convenient form of magneto-testing set having an automatic shunt are shown in Fig. 84.

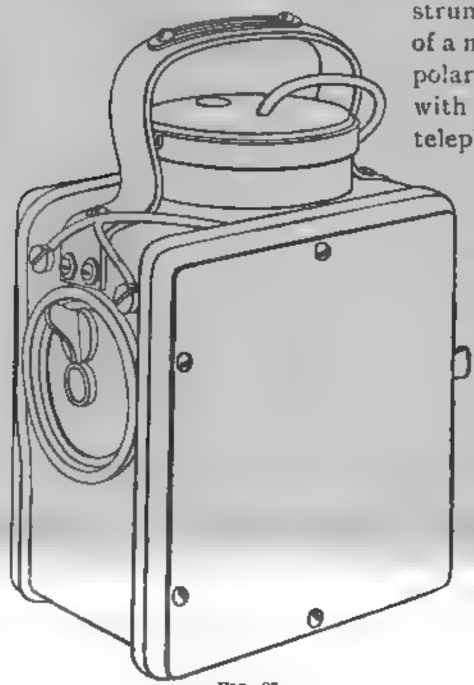


FIG. 83.

263. The polarized bell *R* is here connected in series with the generator *G* when the small switch *S* is in contact with the center button. When the switch is thrown to the left, the call bell is cut out of circuit and the generator only is connected across the line terminals, this condition being advantageous when it is necessary to signal a distant station over a line that may be partially grounded or crossed. When the generator is at rest and the switch thrown to the right, only the telephone *T* is connected in the circuit between the binding posts *L*, *L'*, the generator being short-circuited by the automatic device. The telephone *T* may then be used either as a transmitter or as a receiver for communicating with another party on the line.

When the handle of the generator is turned, the short circuit around the armature winding is opened and the current from the generator, if the switch is turned to the right, will pass through the telephone and to line, thus producing a buzz in the telephone. By means of this, the party testing can often form some idea of the resistance or capacity of a circuit by the loudness of the buzz produced when ringing through the telephone.

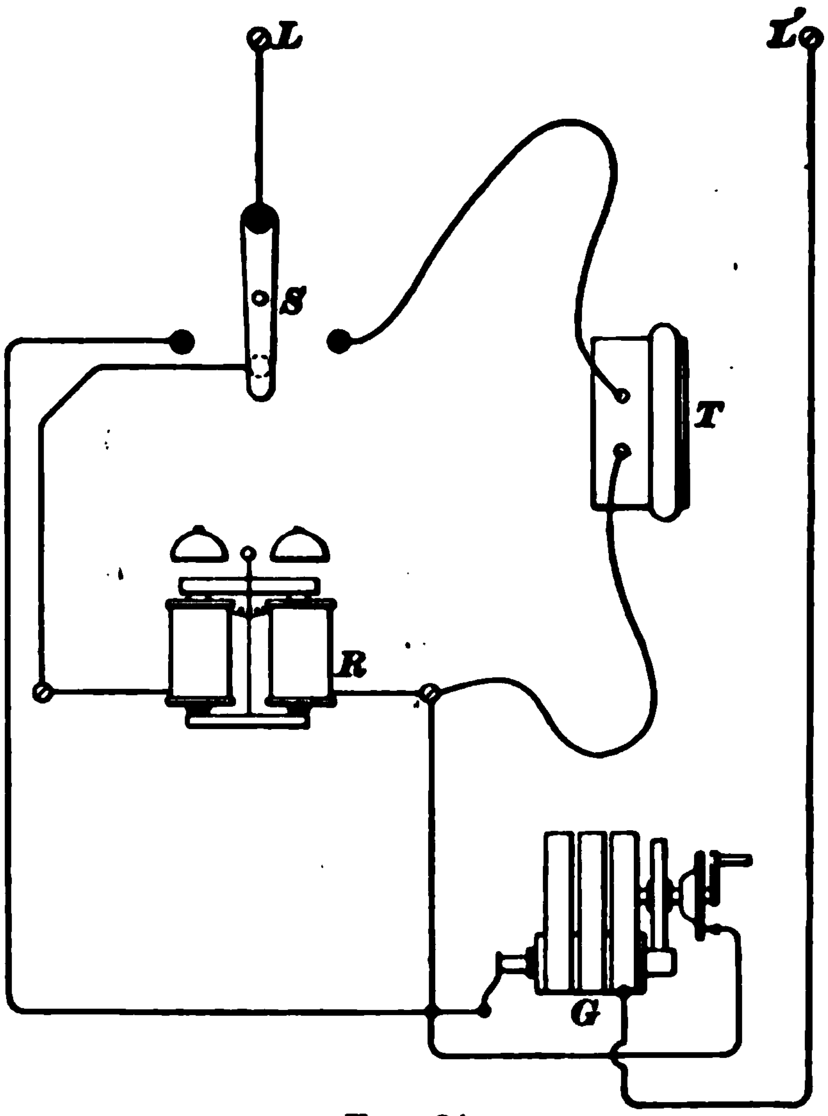


FIG. 84.

264. Continuity Tests.—In testing wires for continuity, the terminals of the magneto set should be connected to the terminals of the wire and the generator operated, the switch of the testing set being thrown so as to include the bell and generator in series. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be used with caution on long lines and cables, because it may be that the capacity of the line wires themselves will be sufficient to allow enough current to flow through the bell to operate it even though the line or lines are open at some distant point.

265. Testing for Crosses.—In testing a line for crosses, either with the earth or with other conductors, one terminal of the magneto set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. A ringing of the bell will, under

these conditions, indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings and also the pull of the generator in turning will indicate in some measure the extent of this cross.

266. An experienced telephone lineman can often tell with considerable accuracy the approximate location of a cross on a line by the sound produced by the bell or by the pull of the generator crank when the generator alone is thrown on the circuit. Here again, however, as in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists if the line under test is a very long one. The insulation may be perfect and yet a sufficient current may pass to and from the line, through the bell, to cause it to sound, these currents of course being due to the static capacity of the line itself.

267. In testing very long lines or comparatively short lines of cable, the magneto set must be used with caution and intelligence, on account of the capacity effects referred to. For short circuits in local testing, however, the results may be relied on as being accurate. Magneto testing sets are commonly wound in such manner that the generator will ring its own bell through a resistance of about 25,000 ohms. They may, however, be arranged to ring only through 10,000 ohms, or, where especially desired, through from 50,000 to 75,000 ohms. The first figure mentioned—25,000 ohms—is probably best adapted for all-around testing work.

CURRENT-DETECTOR GALVANOMETER.

268. In order to test for grounds, crosses, or open circuits on long lines or on cables without the liability to error that is likely to arise in testing with a magneto set, a cheap form of galvanometer for detecting currents may be used. In testing for grounds or crosses, the galvanometer should be connected in series with several cells of battery, and one

terminal of the circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected to the ground and to adjoining wires successively. A sudden deflection of the galvanometer needle may take place whenever the circuit is first closed, this being due to the rush of current into the wire necessary to charge it. If the insulation is good, then the needle of the galvanometer will soon return to zero, but if a leak exists from a line to ground or to the other wire with which it is being tested, the galvanometer needle will remain permanently deflected.

Tests for insulation can be made with considerable accuracy by this method if a battery consisting of about 50 cells is used, but if the resistance of an insulation is to be measured in megohms, the methods to be described under the heading of "Accurate Tests" should be followed.

269. In testing for continuity, the distant end of the line should be grounded or connected with another wire known to be good, and the galvanometer and battery applied, either between the wire under test and ground or between the wire under test and the good wire. In this case, a permanent deflection of the galvanometer needle will denote that the wire is continuous, while if the needle returns to zero, it is an indication of a broken wire.

TESTS WITH TELEPHONE RECEIVER.

270. The importance of the telephone receiver as a testing instrument is greatly underrated and, consequently, is not very extensively used. However, a good receiver is one of the most sensitive detectors of current known, and if connected in series with a battery, it may be used for rough tests in many cases with greater facility than the magneto testing set or the detector galvanometer.

271. Convenient Testing Set.—The ordinary watch-case receiver, with a head-band for attaching it to the ear

of the user, together with one or two small-sized cells of dry battery, form a testing set that, for local work, is unsurpassed, and may be used in testing out cables for grounds or broken wires. If the set is to be portable, the batteries should be small enough to be carried in the coat pocket of the user, and if two cells are used, may be bound together side by side by a wrapping of ordinary adhesive tape. One terminal of the battery is connected to one terminal of the head-receiver, while to the remaining terminals may be connected flexible cords provided with terminals adapted to make contact with the various parts of the circuit that it is desired to test. This arrangement, while being capable of detecting the most feeble currents, has the further advantage of being light and of allowing the complete freedom of both hands of the user.

272. Method of Using Receiver.—In using the receiver for making rough tests for grounds or crosses in a cable, one terminal of the testing circuit, including the receiver and batteries, should be connected with the sheath of the cable, while the other terminal should be connected with the wire under test, which should be free from the other wires at each end. All the other wires in the cable should be bunched together at the near end of the cable and connected with the sheath. The wires at the distant end of the cable must all be carefully separated from each other and from the sheath, so that there is no possibility of a cross existing between them at that end. A click will be heard on closing the circuit with the wire under test, whether or not the wire is grounded, this being due to the fact that a small amount of current will flow into the wire even if it is properly insulated. If the wire is grounded, the flow of current will continue as long as the terminal is applied to the wire, but if the wire is well insulated, the flow will cease as soon as the wire has received its full charge. In order, therefore, to guard against misleading results, the terminal of the testing set should be tapped against the wire several times in succession; a continuance of the clicks will then

indicate that the wire is grounded, while the cessation of the clicks after a few taps will indicate that the insulation is good.

273. In testing for continuity with the receiver, all the wires should be bunched together at the distant end of the cable and connected with one terminal of the test battery by a separate wire leading to the end of the cable where the test is to be made. The other terminal of this battery should be connected to one terminal of the receiver, the other terminal of which may be applied to the separate wires at the near end of the cable, the wires at this end all being carefully separated from one another. A continuation of the clicks upon tapping will in this case indicate that the wire being tested is continuous, while the cessation after a few taps will indicate that it is broken. It is probably better, in making this test, to use an ordinary vibrating bell instead of a receiver, for then, if the wire is only partially ruptured so as to offer a very high resistance, it will not allow enough current to pass to ring the bell, while it might allow enough to pass to produce a decided click in the receiver.

IDENTIFYING WIRES IN CABLES.

274. It is frequently necessary when a certain wire has been picked out at one end of a cable to identify that same wire at the other end in order that connection may be made with it. In order to do this, the wire desired should be grounded at one end, being carefully insulated from all the other wires. At the other end the wires should all be separated from each other and be free from the ground. A circuit containing a battery and a receiver or galvanometer detector or ordinary vibrating bell should then have one of its terminals grounded, while the other terminal should be applied successively to the various wires in the end of the cable. A continuation of the clicks in the receiver, a permanent deflection of the galvanometer

detector, or a ringing of the vibrating bell will indicate when the wire desired has been touched.

275. Identifying Without Cutting.—It is frequently desirable to identify a wire at some intermediate portion of a cable without cutting the wire. This may be done by removing the sheath, or the outer coating, if the cable has no sheath, and loosening up the wires so that each one may be touched. The same test as that in the preceding article may then be made by using a needle-pointed terminal to the testing circuit that may readily pierce the insulation and make contact with the conductor within.

ACCURATE TESTS.

MEASUREMENTS OF RESISTANCE.

276. The Wheatstone Bridge.—Measurements of resistance are usually made by means of the Wheatstone bridge, this instrument being very accurate for all resistances except those very large or very small, and possessing the additional desirable features of great simplicity and portability. The methods of using the Wheatstone bridge have been sufficiently treated in *Electrical Measurements*, and need not be further dealt with here. It may be said, however, that the form of bridge best adapted for general testing purposes has a rheostat capable of being adjusted to any resistance from 1 ohm to about 11,000 ohms. The arms by which the ratio is obtained should be capable of having the values of 10, 100, and 1,000 ohms, thus being able to obtain multipliers from $\frac{1}{100}$ to 100.

277. The galvanometer for ordinary resistance measurements is preferably mounted in the same case as the resistance coils of the bridge and with the keys for opening and closing the galvanometer and battery circuits. The galvanometer most suited for this work consists of a special

form of D'Arsonval, in which the coil forming the needle is suspended in the field of a powerful permanent magnet. These galvanometers have the advantage of not being affected by the proximity of other magnetic fields, and are, moreover, quite sensitive. Of course, for the most accurate tests, some form of reflecting galvanometer should be used. In some portable bridges, a battery is mounted in the same case with the other parts of the apparatus, this forming a very desirable feature and adding greatly to the ease with which rapid tests may be made, inasmuch as it is not necessary to carry extra batteries and to connect them up every time a test is to be made.

278. High Resistance by Wheatstone Bridge.—It is sometimes desirable to determine by means of a Wheatstone bridge a resistance that is too high to be measured by it in the ordinary direct manner. Provided another resistance is at hand that can be accurately measured by the bridge, the unknown resistance, if not too high, may be determined in the following manner: First measure the lower resistance and let it be y ohms. Then connect this resistance y in parallel with the high unknown resistance and measure the combined resistance of the two joined in parallel and let this be z ohms. Then, if x is the unknown high resistance whose value is desired, we have

$$z = \frac{xy}{x + y},$$

from which we get

$$x = \frac{yz}{y - z}. \qquad \textbf{(3.)}$$

Where x alone is higher than can be directly measured on the bridge, y should be as high as can be *accurately* measured on the bridge, or as high as can be obtained, say at least several thousand ohms. When y is accurately known or measured and x is not too high, this is a very good method. This method may be used to check up resistances that have been measured separately.

279. Measurement of Line Resistance.—In measuring the resistance of a line by means of the Wheatstone bridge, the terminals of the line circuit should be connected in the unknown arm of the bridge. Sometimes it occurs in the case of a grounded circuit that earth currents will interfere to such an extent as to render accuracy impossible. In this case, if a parallel wire is available, the resistance of which is known, they may be connected together at the distant end and the resistance of the two in series measured. The resistance of the first will then be the difference between the total measured resistance and that of the known wire.

280. Line Resistance.—A method for measuring the resistance of a line wire was given in *Electrical Measurements*. A better method, where there are three or more line wires, or two line wires and a ground circuit, between the same two offices is as follows: Let the resistance of three line wires be x, y, and z, respectively. At the distant station have the ends of x and y joined together. Then, by means of a Wheatstone bridge at the home station, measure the resistance of the loop so formed and let it be a ohms. Then have the distant ends of x and z joined and measure the resistance of this loop, calling it b ohms. Similarly, have the distant ends of y and z joined, measure the resistance of this loop, and call it c ohms.

Then,

$$x + y = a.$$

$$x + z = b.$$

$$y + z = c.$$

Solving these equations for x, y, and z, we get

$$x = \frac{a + b - c}{2}. \qquad (4.)$$

$$y = \frac{a + c - b}{2}. \qquad (5.)$$

$$z = \frac{b + c - a}{2}. \qquad (6.)$$

Hence, the resistance of any one or of each one of the the three line wires may be calculated from these three measurements.

281. Resistance of Ground-Return Circuits.—The resistance of the ground-return circuit may be measured by the preceding method when there are two line wires between the same two offices. Let the resistance of the two wires be x and y ohms, respectively, and that of the ground circuit be z ohms. Measure the resistance of the loop formed by having the two distant ends of the two line wires joined together and call it a ohms. Then have the x wire grounded at the distant office and measure the resistance between the home ground plate and the home end of the x wire, and call it b ohms. Similarly, have the distant end of the y wire grounded, and measure the resistance between the home ground plate and the home end of the y wire, and call it c ohms. Then the resistance of the ground return z may be calculated by formula **6.** Usually most of this resistance z is located at the contact surfaces between the plates and the ground, as already explained in *Telegraphy*, Part 2. The resistance of a good ground return should not exceed 10 ohms. It is evident that we may also obtain the resistance of the two line wires by substituting the quantities a, b, and c in formulas **4** and **5.**

EXAMPLE.—It was desired to measure the resistance of two wires x and y, and also the resistance of the ground path z between two stations A and B. The party making the test at A instructed station B to join the wires x and y together. A measurement of the resistance of the loop so formed was made at A with a Wheatstone bridge, giving 2,490 ohms. The operator at B was then instructed to ground the wire x, and the operator at A measured the resistance between his end of the wire x and his ground; this gave 1,270 ohms. The operator at B was then instructed to ground the wire y, and the operator at A found the resistance between his end of y and his ground to be 1,300 ohms. What was the resistance of each wire and of the ground path?

SOLUTION.—By formulas **4, 5,** and **6,** in which $a = 2{,}490$, $b = 1{,}270$, and $c = 1{,}300$, we get the desired resistances:

$$x = \frac{2,490 + 1,270 - 1,300}{2} = 1,230 \text{ ohms};$$

$$y = \frac{2,490 + 1,300 - 1,270}{2} = 1,260 \text{ ohms}.$$

The ground path

$$z = \frac{1,270 + 1,300 - 2,490}{2} = 40 \text{ ohms. Ans.}$$

282. Elimination of Earth Currents.—Earth currents will often render measurements of line resistances, where the ground is used as a part of the circuit, as in the last method, very unreliable. These currents may oppose or aid the testing current. When the earth currents are fairly steady, their effect may be eliminated by making a measurement, then reversing the battery and making another measurement. The average of the two measurements should be taken as the resistance of the circuit For good results, the earth current should not only be steady but it should also be small compared with the testing current.

INSULATION TESTS.

283. In making insulation tests, the general methods outlined in *Electrical Measurements*, under the heading, "Insulation," may be followed in some cases. The method generally used, together with the proper apparatus, will, however, be described here in some detail.

284. Galvanometer.—For tests of extreme accuracy, the Thomson or sensitive reflecting galvanometer is best suited, but the use of this instrument is attended with many difficulties that render it unfit for many forms of practical work. As a laboratory instrument, however, where it can be properly shielded from the magnetic fields set up by neighboring electrical machinery or by trolley or lighting circuits, this instrument is unexcelled. The D'Arsonval galvanometer, however, is sensitive enough for nearly all practical work, and possesses the advantage of being

entirely free from the effects of external fields It is now made in portable form, so that it can be unpacked and set up in a few moments.

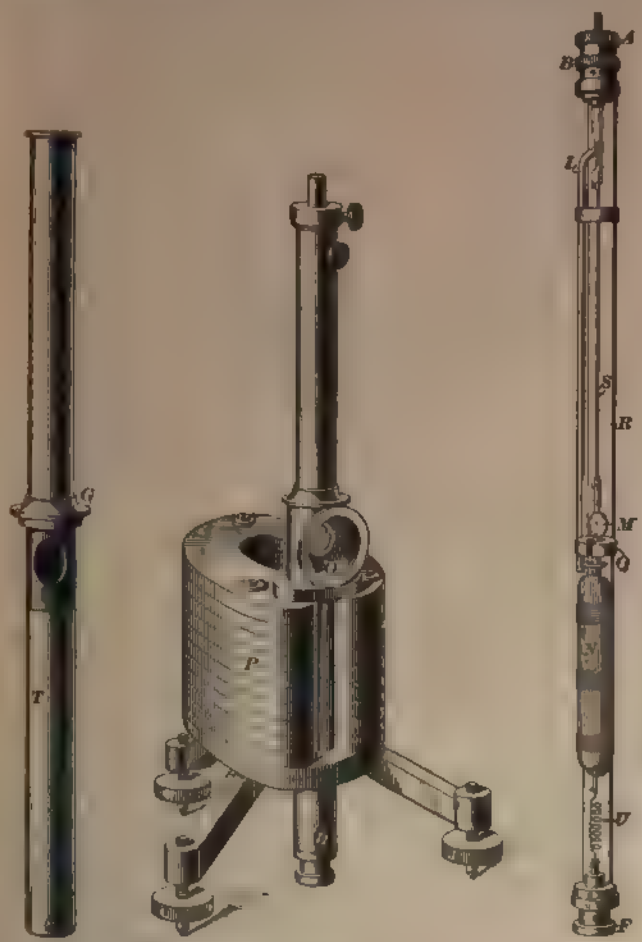


FIG. 85

285. D'Arsonval Galvanometer.—One form of D'Arsonval galvanometer used in this country is shown in Fig 85, in which P are the permanent magnets by which the field of force in which the coil is suspended is maintained.

The needle and suspension are mounted within the tube T, shown at the left-hand portion of this figure, this tube being removable from the frame of the instrument when it is desired to make any changes or repairs of the working parts within. The system, as the coil N and its supporting parts are termed, is shown in detail at the right of the figure. R is a rib supporting at the top and the bottom the torsion heads B and F. The rectangular coil N consists of many turns of fine wire, and secured to it above is a mirror M for reflecting a ray of light through the window O

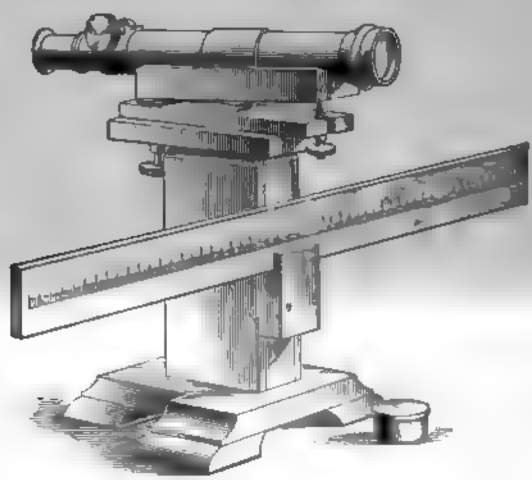


FIG. 86.

of the frame. The coil is suspended by a straight, elastic fiber S of some conducting material, such as phosphor-bronze, while the lower part of the coil is connected by a coiled spring U, usually of the same material, with the lower torsion head F. Current is led through the coil N by means of the suspension fiber S and the coil spring U. The torsion of the suspending fibers tends to hold the coil in a certain normal position, which position may be regulated by turning the torsion heads B and F, usually by turning B alone. When it is desired to move the instrument, the thumbscrew A at the top of the system may be tightened,

thus drawing up the rod L and causing the fork carried by its lower end to engage a disk Q, which raises the coil just enough to remove its weight from the suspension fiber S.

This galvanometer is used in the same manner as the reflecting galvanometers described in *Electrical Measurements*. The lamp and scale may be used as shown in Fig. 988 of that section, but a better way is to mount a telescope carrying a horizontal scale directly in front of the galvanometer, in such manner that portions of the horizontal scale will be reflected by the mirror of the galvanometer into the tube of the telescope. Such a telescope and scale combined is shown in Fig. 86. Special scales are provided for this purpose, the numbers on which are reversed, so that when a reflection in the mirror is viewed through the telescope, they will appear normal. This method of reading the galvanometer is more desirable than that using the lamp, because the readings may be made with greater accuracy by means of a cross-hair in the telescope, and, further, because the presence of a lighted lamp is not always necessary. However, a lamp placed to illuminate the scale (not the galvanometer mirror) will often render the reading of the scale much easier.

286. Galvanometer Shunts.—The shunt accompanying the galvanometer should, of course, be adjusted to the particular resistance of the galvanometer coil, and should preferably have multiplying values of 10, 100, and 1,000.

287. Method of Measuring Insulation Resistance.—The method usually followed of measuring insulation resistance with a galvanometer is to first obtain the deflection through a known resistance, using a suitable known shunt around the galvanometer, with the given battery, and from it to calculate the deflection in scale divisions that would be produced were the entire current of the same battery to pass through the galvanometer and a resistance of 1 megohm. This latter quantity is called the *working constant* of the galvanometer. After the working

constant is obtained, the deflection is taken with the insulation resistance of the line or cable substituted for the known resistance. In taking the galvanometer constant, it is usually necessary to use the shunt having a multiplying power of 1,000 (called the $\frac{1}{999}$ shunt), for otherwise the deflection would be too large to be readable.

288. Taking the Constant.—The circuits for taking the galvanometer constant are shown in Fig. 87, where G is the galvanometer, S the shunt, B a battery of 50 or 100 cells, and R a standard resistance, usually of 100,000 ohms, i. e., $\frac{1}{10}$ of a megohm. Upon closing the key K, a certain deflection d will be noted upon the galvanometer. If the shunt used has a multiplying power of 1,000,

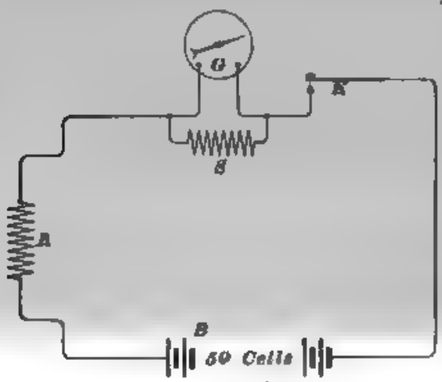


FIG. 87.

it is evident that without the shunt the deflection would have been 1,000 times as large, could it have been measured. Further, if a resistance of 1 megohm had been used instead of $\frac{1}{10}$ megohm, the deflection would have been only $\frac{1}{10}$ of d. Therefore, we may say that the deflection K produced by the current from the battery, passing through 1 megohm and through the galvanometer, without the shunt, would have been

$$K = \frac{1{,}000 \times d}{10}.$$

If m represents the multiplying power of the shunt, d the deflection, and R the resistance *expressed in megohms*, then the constant K may be expressed by the formula

$$K = R \times m \times d. \qquad \textbf{(7.)}$$

The following general rule, therefore, may be given for calculating the constant:

Multiply the deflection by the multiplying power of the shunt and by the resistance in the standard resistance box expressed in megohms or a fraction thereof.

In the case just cited, if the deflection d was 197 scale divisions, then the constant K would be equal to

$$197 \times 1{,}000 \times \tfrac{1}{10} = 19{,}700.$$

EXAMPLE 1.—In taking the constant, a $\frac{1}{10}$-megohm box was used and a deflection obtained of 247 scale divisions, the multiplying power of the shunt being 1,000. What was the constant?

SOLUTION.— $247 \times 1{,}000 \times \frac{1}{10} = 24{,}700$. Ans.

EXAMPLE 2.—In taking the galvanometer constant, a deflection of 143 scale divisions was obtained through a standard resistance of 2 megohms, the multiplying power of the shunt being 100. What was the constant?

SOLUTION.— $143 \times 100 \times 2 = 28{,}600$. Ans.

289. Deflection Through Insulation.—After taking the constant, the insulation resistance of the cable or line is substituted for the standard resistance, the connections being then substantially those shown in Fig. 88. All the wires of the cable, except the one being measured, should be bunched together and connected with the sheath, the sheath itself being grounded. At the start use, as a precaution, a small shunt, the $\frac{1}{999}$ or the $\frac{1}{99}$, whose multiplying powers are 1,000 and 100, respectively, and increase the resistance of this shunt until a suitable deflection is obtained. If the insulation resistance is rather high, usually no shunt (that is, a shunt of infinite resistance) will be required, and the shunt box can be cut out entirely, which is done by removing all the movable plugs. Upon

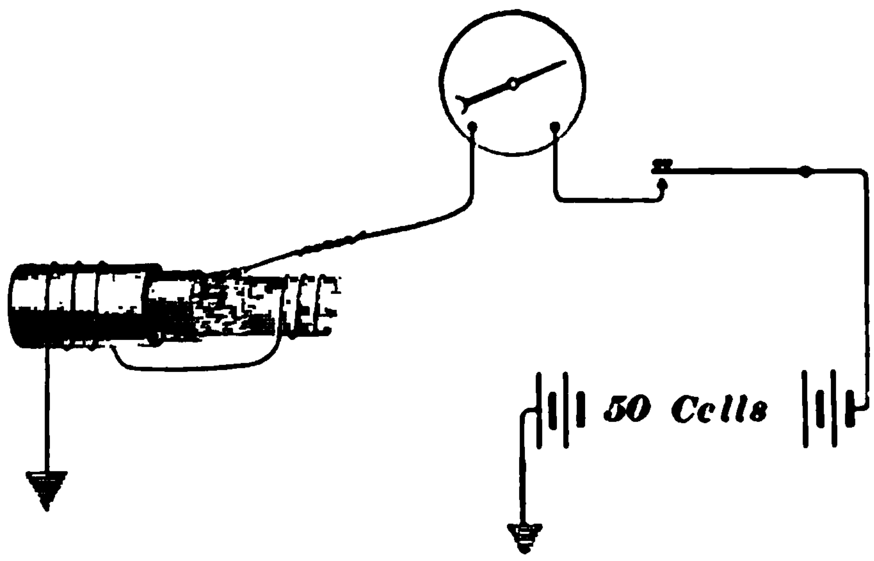


FIG. 88.

the closure of the key, a certain deflection of the galvanometer will be obtained at once, but this deflection, instead of remaining constant as it did with the circuits shown in Fig. 87, will be seen to slowly diminish, this being due to the electrification of the cable. The diminishing deflection would seem to indicate that the insulation resistance of the cable was increasing by the passage of the current; but this effect is due to electrification, which phenomena, as was pointed out in *Electrical Measurements*, is not thoroughly understood, but may be stated as being in the nature of a soaking in of the charge of electricity into the insulation. After about half a minute, on a short length of ordinary telephone cable, the electrification will practically have ceased; but the rule is, in taking insulation resistance, to allow one minute for electrification, after which the reading is taken.

290. Calculation of Insulation Resistance.—In making insulation tests at the factory, the whole cable, excepting the two ends, of course, is submerged in a tank of salt water. The manufacturers generally use as high as 200 volts in making this test. This requires a known resistance of 500,000 ohms (half a megohm) and the $\frac{1}{999}$ shunt of the galvanometer in order to obtain the constant K.

The constant K was obtained by calculating the deflection that the given electromotive force would have produced if the total resistance of the circuit were 1 megohm and no shunt had been used around the galvanometer. In taking the deflection through the insulation resistance, a certain deflection at the end of one minute was observed, which will be called d', the galvanometer shunt this time being one whose multiplying power will be called m'. Without this shunt it is evident that the deflection would have been m' as large, i. e., $m' \times d'$, could it have been measured directly. It is also evident that the deflections, if no shunts are used, will vary inversely as the resistance in the circuit with the galvanometer, and, therefore, where X is the required insulation resistance, the following proportion will hold:

$$X : 1 :: K : d' \times m'.$$

Solving for X, we have

$$X = \frac{K}{d' \times m'}. \qquad (8.)$$

That is, *the insulation resistance is equal to the constant of the galvanometer divided by the product of the multiplying power of the second shunt used and the deflection obtained through the insulation.*

When the shunt resistance has an infinite value, that is, when it is cut out of the circuit and no shunt is used, the value of m' is 1. In such a case, X would be simply the constant K divided by the deflection d'.

291. This method is not strictly accurate, because the combined resistance of the galvanometer and shunt should be added to that of the known resistance and to that of the insulation resistance in making the computations. However, the error introduced by neglecting this is usually so small that it is always neglected in making ordinary insulation tests.

In order to determine the insulation resistance per mile, multiply the insulation resistance of the cable as measured by its length expressed in miles or a fraction thereof.

EXAMPLE 1.—In taking the constant of a galvanometer for an insulation test, a deflection of 184 scale divisions was obtained with a $\frac{1}{10}$-megohm box and with a multiplying power of the shunt of 1,000. The deflections, taken through the insulation resistance of 3 wires, one at a time, in a cable 10,123 feet long, with a shunt whose multiplying power was 10, were as follows: 23, 19, and 25 scale divisions, respectively. What was the insulation resistance of each of the wires?

SOLUTION.—The constant of the galvanometer is equal to

$$184 \times 1{,}000 \times \tfrac{1}{10} = 18{,}400.$$

Insulation resistance, first wire, $\frac{18{,}400}{10 \times 23} = 80$ megohms. Ans.

Insulation resistance, second wire, $\frac{18{,}400}{10 \times 19} = 96.84$ megohms. Ans.

Insulation resistance, third wire, $\frac{18{,}400}{10 \times 25} = 73.6$ megohms. Ans.

EXAMPLE 2.—What is the insulation resistance per mile of each of the wires in the preceding example?

SOLUTION.—Length of cable $= \frac{10,123}{5,280} = 1.917$ miles.

Insulation resistance per mile, first wire, $80.0 \times 1.917 = 153.36$ megohms. Ans.

Insulation resistance per mile, second wire, $96.84 \times 1.917 = 185.64$ megohms. Ans.

Insulation resistance per mile, third wire, $73.6 \times 1.917 = 141.09$ megohms. Ans.

MEASUREMENT OF LINE CAPACITY.

292. The simplest and probably the most satisfactory method for measuring the capacity of a line or cable is to compare the capacity to be measured with that of a standard condenser. It is first necessary to obtain the deflection of the galvanometer needle when the standard condenser is

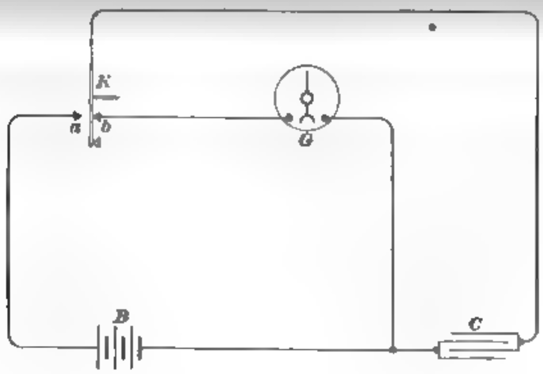


FIG. 89.

discharged through it. For this purpose the apparatus is arranged as shown in Fig. 89, in which G is the galvanometer, C the standard condenser, B a battery of from 1 to 15 cells, and K a discharge key resting normally against the contact b, but capable of being depressed against the contact a. The capacity of the condenser C should, if possible,

be adjustable from about $\frac{1}{10}$ to 1 microfarad, but in case an adjustable condenser is not available, one having a capacity of about $\frac{1}{10}$ microfarad will be found most suitable for telephone work.

When the key is depressed, a current from the battery charges the condenser. The charging should be allowed to continue for about 15 seconds, in order to give the charge a chance to soak in. The key should then be suddenly released, which will establish such connections as to allow the condenser to discharge through the galvanometer. A certain throw or kick of the galvanometer needle will take place, and this extreme reading should be noted down.

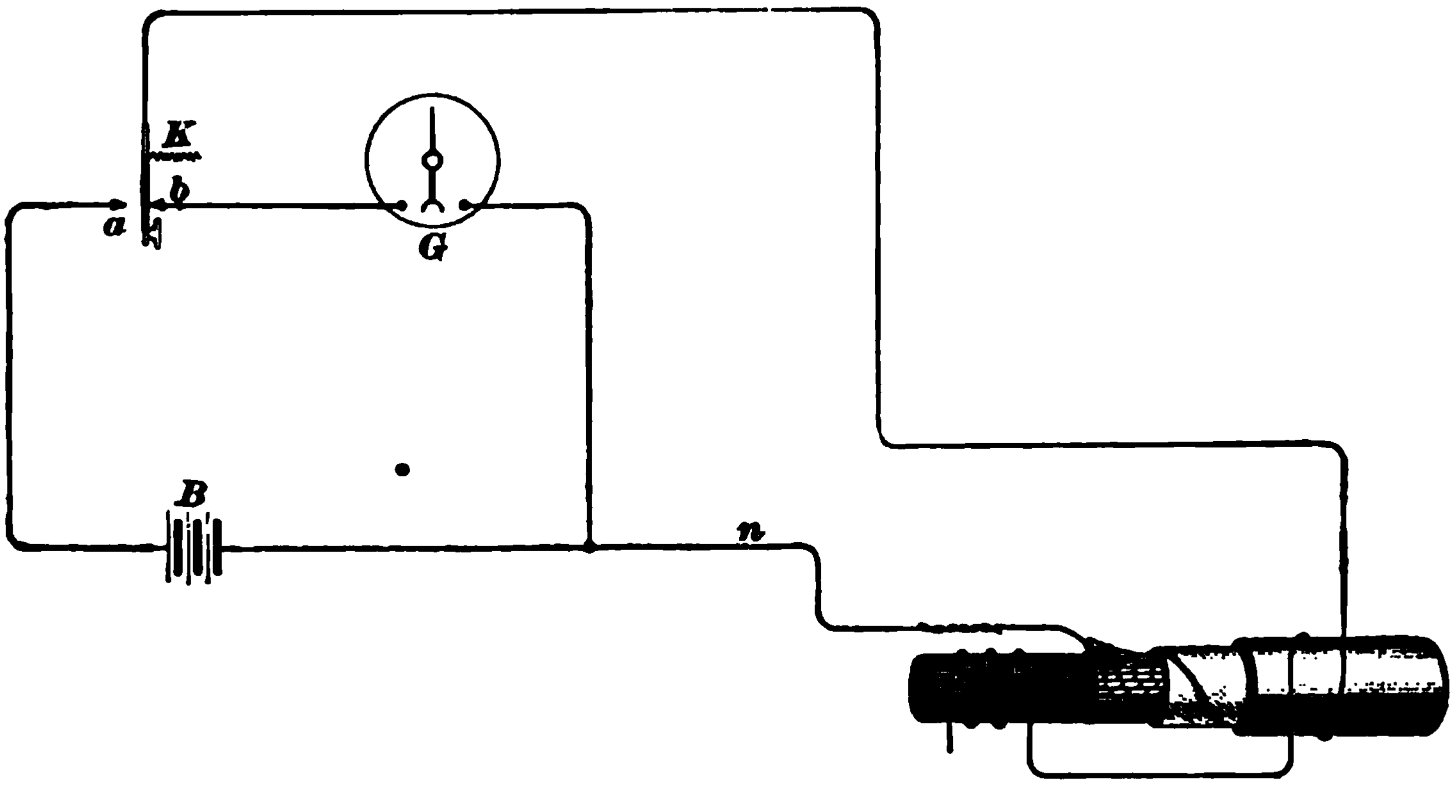


Fig. 90.

Several readings should be taken to avoid error and to obtain an average. The cable or line is then substituted for the condenser, as shown in Fig. 90, where the wire *n* leading from the galvanometer and battery is connected to the wire of the cable to be measured, all the other wires being insulated from it and connected with the sheath of the cable. The key *K* should be connected to the sheath, as shown. If the line whose capacity is being measured is of bare wire, the wire *n* from the battery and galvanometer should be connected to it, while the wire from the key should be grounded. Several readings are then taken on the galvanometer, and the average of them obtained as before.

Between readings, the condenser or line, as the case may be, should be fully discharged by holding the key in the discharging position for at least 5 seconds.

If no shunt is used on the galvanometer, or if the same shunt is used in each case, the two capacities will vary in proportion to the respective readings of the galvanometer; thus, calling d the deflection obtained with the standard condenser, d' that with the cable, Q the capacity in the standard condenser, and Q' the capacity of the cable, we have

$$Q' : Q :: d' : d;$$

or,
$$Q' = \frac{Q \times d'}{d}. \qquad \textbf{(9.)}$$

If it is necessary to use a shunt in taking the readings from the cable or condenser, the corresponding deflections should be multiplied by the multiplying power of the shunt before using them in the formula. The use of a shunt in capacity tests should be avoided if possible.

The capacity per mile is found by dividing the total capacity by the length of the cable in miles. The best results are obtained when the capacity of the standard condenser is very nearly equal to that of the condenser, and the deflections therefore nearly the same.

Example.—A test was made to determine the capacity of a cable. The capacity of the standard condenser was 1 microfarad. The deflection or throw from the standard condenser was 37 divisions, and that from the cable was 42. What was the capacity of the cable ?

Solution — $Q' = \frac{42 \times 1}{37} = 1.135$ microfarads. Ans.

LOCATION OF FAULTS.

293. Faults on a line may be of two kinds: The line may be entirely broken or it may be unbroken, but in contact with some other conductor or with the ground. The former fault is termed a *break;* the latter, a *cross* or *ground.*

294. A **break** may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall or have its insulation impaired so as to form a cross or ground. A **cross** may be of such low resistance as to form a short circuit, or it may possess high resistance, thus forming what is termed a *leak*. The location of faults is a matter often involving much ingenuity and mathematical knowledge. Some methods for locating between what two offices a fault occurs were given in *Telegraphy*, Part 2, under the heading "Tests With Relay and Key." For locating the ordinary faults, such as usually occur on lines or cables, the following methods may be relied on.

TESTS FOR LOCATING A BREAK.

295. The location of a break in a wire can be determined by capacity tests, as the capacity of the part of a wire bears the same relation to the capacity of the whole wire as the length of the part does to that of the whole.

When one good wire, having the same capacity per mile, is accessible, a condenser need not be used, but, instead, deflections may be taken on the broken wire and on the good wire. Let D be the throw on the broken wire and D' the throw on the good wire. L is the distance to the break and L' the total length of the good wire. Then,

$$D : D' :: L : L';$$

or,

$$L = \frac{D \times L'}{D'}. \qquad \textbf{(10.)}$$

EXAMPLE 1.—A test was made to find a break in a cable conductor near to which ran another sound wire. The throw on the broken conductor was 35 divisions and that on the good wire was 80 divisions. What was the distance to the break, the total length of the cable being 3,100 feet?

SOLUTION.—Using formula **10**,

$$L = \frac{35 \times 3,100}{80} = 1,356 \text{ ft.} \quad \text{Ans.}$$

EXAMPLE 2.—A break occurs in a cable 3 miles long. It is known that the capacity of the entire conductor was .39 microfarad per mile, or 1.17 microfarads in all. Upon testing, it is found that with a standard condenser of $\frac{1}{3}$ microfarad and a suitable battery and shunt to the galvanometer, the deflection is 98, while with the same shunt and battery, the deflection obtained from one end of the cable is 141. How far from the testing end is the break?

SOLUTION.—Using formula **9**, $Q = \frac{1}{3}$, $d = 98$, $d' = 141$.

$$Q = \frac{\frac{1}{3} \times 141}{98} = .4796 \text{ microfarad.}$$

$$\text{Distance from testing end} = \frac{.4796}{.39} = 1.23 \text{ miles. Ans.}$$

EXAMPLES FOR PRACTICE.

1. In a test for the capacity of a cable, the capacity of the standard condenser was 2 microfarads. The throw produced by the condenser was 53 divisions and that by the cable was 32 divisions. What was the capacity of the cable? Ans. 1.207 microfarads.

2. A test was made to locate a break in a cable conductor. A sound wire was accessible. The throw on the broken wire was 29 divisions and that on the good wire was 75 divisions. The length of the tested cable was 5,760 feet. What was the distance to the break?
Ans. 2,227 ft.

TESTS FOR LOCATING GROUNDS.

296. These faults occur much more frequently than breaks and are often difficult to locate, especially if more than one ground or cross occurs on the same line.

297. Tests Without Available Good Wire.—The existence of a wire whose insulation and continuity are known to be perfect (such wires are usually termed good wires) is often a great aid in helping to locate a cross. Where no good wire is available, however, the following method may be used: Carefully insulate both ends of the wire from the ground and from other conductors. A Wheatstone bridge with a sensitive galvanometer is then connected

between one end of the wire and the ground, as shown in Fig. 91, and the resistance of that end of the line wire, through the fault, to the ground is measured. Let this resistance be r. The same test is now repeated at the other end of the line, and a resistance r' is observed. Call z the

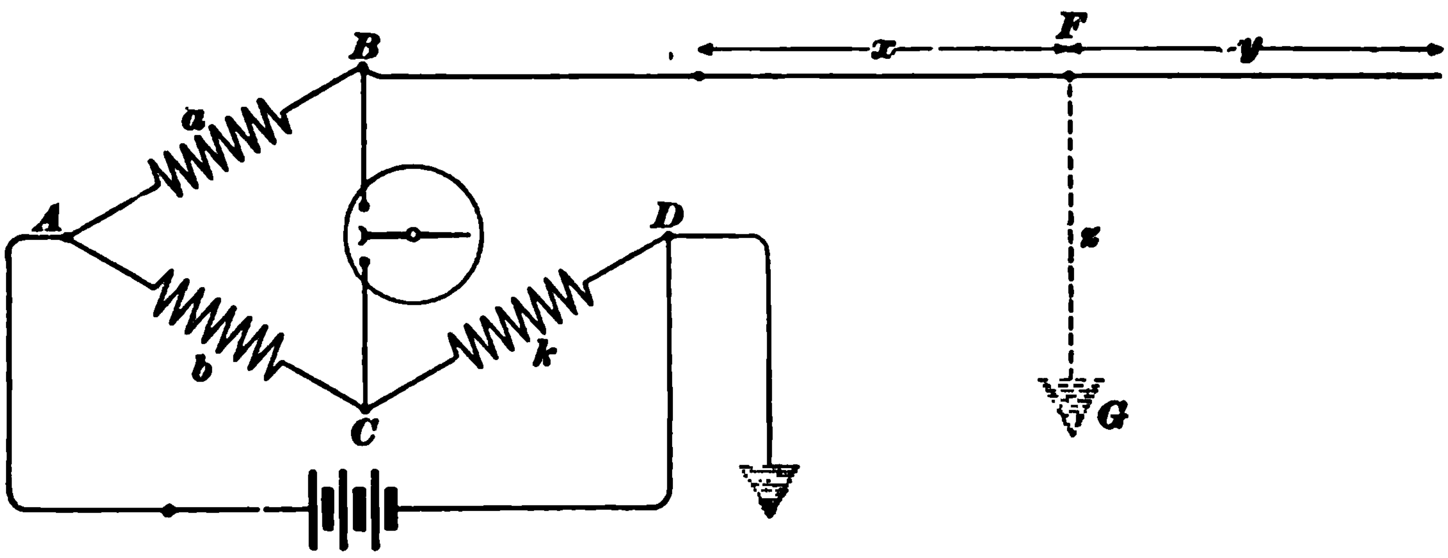


FIG. 91

resistance of the fault itself, x the resistance of the line wire from the first end to the fault, and y the resistance of the remaining portion of the line wire. The first resistance measured, r, is the combined resistance of the first portion of the line wire and the resistance of the fault. Thus,

$$r = x + z.$$

Similarly, $$r' = y + z.$$

Calling L the resistance of the line, we have the equation

$$L = x + y.$$

Solving these three equations for x, y, and z, we obtain

$$x = \frac{r - r' + L}{2}. \qquad (11.)$$

$$y = \frac{r' - r + L}{2}. \qquad (12.)$$

$$z = \frac{r + r' - L}{2}. \qquad (13.)$$

The value of L, if not already known, may be calculated from the known size and length of the wire.

EXAMPLE.—A test was made for a fault where no good wire was available. The resistance measured at the first station was 600 ohms, and that at the second station 630 ohms, and the resistance of the line was 1,150 ohms. What was the resistance to the fault from the first station? from the second station? What was the resistance of the fault?

SOLUTION.— $r = 600$, $r' = 630$, $L = 1,150$.

$$z = \frac{600 + 630 - 1,150}{2} = 40 \text{ ohms. Ans.}$$

$$x = \frac{600 - 630 + 1,150}{2} = 560 \text{ ohms. Ans.}$$

$$y = \frac{630 - 600 + 1,150}{2} = 590 \text{ ohms. Ans.}$$

EXAMPLES FOR PRACTICE.

1. A test for a fault was made upon an aerial line of 1,112 ohms resistance. The resistance of the line was 12.92 ohms per mile. The resistance measured at the first station, through the fault, was 630 ohms, and that at the second station 549 ohms. What was the resistance of the fault? How far was it from the first station, and how far from the second?

Ans. The resistance of the fault was 30 ohms. The distance from the first station to the fault was 46 mi. 774 yd. The distance from the second station was 39 mi. 1,108 yd.

2. A wire touched the ground so that there was no resistance z in the fault. A test was made at the station, and the unplugged resistance in the rheostat amounted to 326 ohms. What was the distance to the fault, the resistance of the wire being 16.1 ohms per mile?

Ans 20 mi. 438 yd.

298. Test From One End Only and Without an Available Good Wire.—The following method for locating a partial ground or an escape is about the only way where there is no *available good wire* and when the tests must be made *from one end only*. However, it is rather unreliable in practice, because the resistance of the partial ground may change between the two measurements and so give a more or less incorrect result, and, moreover, the normal resistance of the line must be known from some

previous measurement or calculated from the length, size, and conductivity of the line wire. Let this resistance be a. Then measure the resistance of the line $B B'$, with the distant end grounded, as shown in Fig. 92, and call this c.

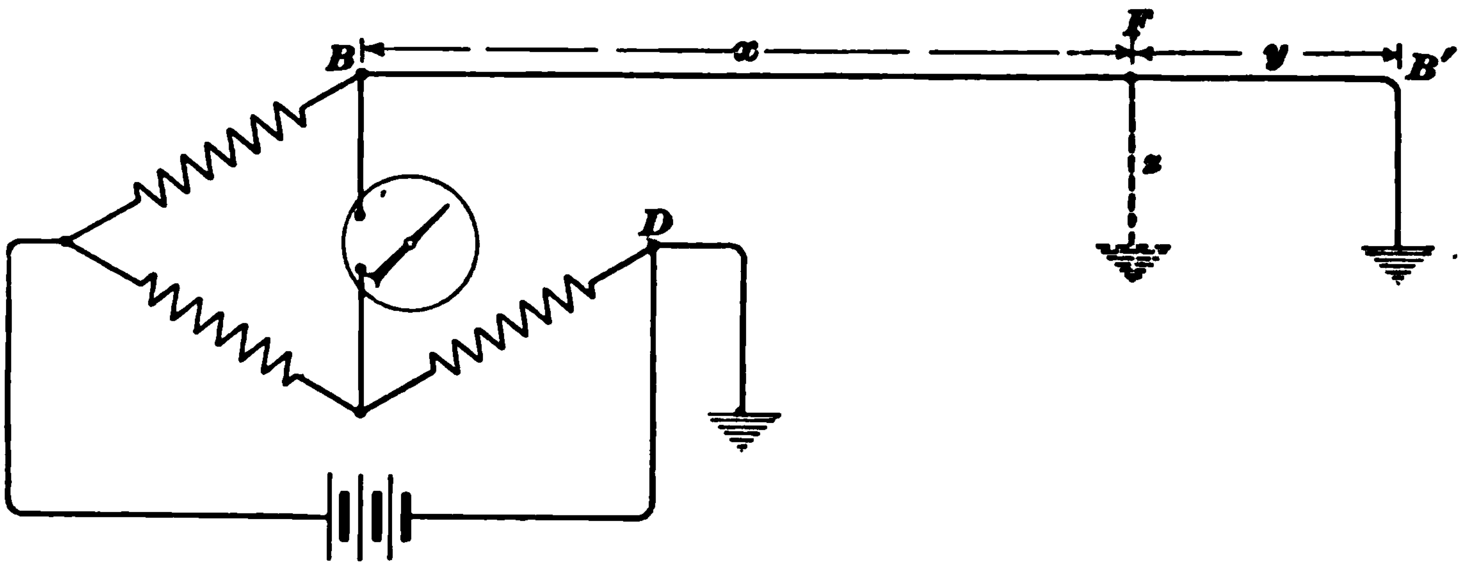


FIG. 92.

Also, measure the resistance with the distant end open, as in Fig. 91, and call this b ohms. Then the resistance x to the partial ground from the testing station is given by the following formula:

$$x = c - \sqrt{(b - c)\,(a - c)}. \qquad \textbf{(14.)}$$

By dividing x by the resistance per unit length of the wire, known from some previous measurements or by its size from a table, the distance to the partial ground is obtained.

NOTE.—Formula **14** is derived as follows: In Fig. 91, let the resistance of the home end of the line to the point F, where the partial ground occurs, be x, from F to the distant end be y, and the resistance of the fault be z ohms. Then, calling a the normal resistance of the whole line,

$$x + y = a.$$

When the partial ground is present but the distant end open,

$$x + z = b.$$

Finally, when the partial ground is present and the distant end grounded, y and z are in parallel with each other but in series with x; then,

$$x + \frac{y\,z}{y + z} = c.$$

Solving the above three equations for x, we get the resistance from the testing station to the partial ground or escape

$$x = c \pm \sqrt{(b - c)(a - c)}.$$

Evidently the minus sign (−) must be used, because x cannot be greater than c.

299. Ground on a Line of Known Resistance.—Where there is a dead ground on a line whose length and resistance are known, it is a simple matter to locate the distance to the dead ground from the testing station. Let a be the known resistance of the line and l the length of the line in miles; then, $\frac{a}{l}$ is the normal resistance of the line per mile. To locate the position of a dead ground on this line, measure the resistance between the home end of the line and the ground and let this be c ohms. Then, the number of miles X_m from the testing station to the dead ground is given by the formula

$$X_m = \frac{c\,l}{a}. \qquad \textbf{(15.)}$$

300. Varley Loop Test.—Where there is an available good wire, the Varley loop method is probably the most convenient and best method for locating a ground or cross

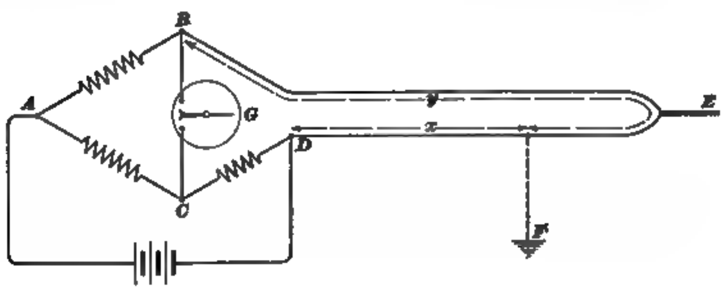


FIG. 93.

on a line. The distant ends of the good and bad wires are joined together and the resistance of the loop so formed is measured with the Wheatstone bridge, if not already known from some previous measurement, by connecting as shown

in Fig. 93. G is a reflecting galvanometer connected across the arms of a Wheatstone bridge in the ordinary manner; $A\,B$ and $A\,C$ are the ratio arms of the bridge, and $C\,D$ is the rheostat or variable arm. $D\,E$ is the faulty line, $B\,E$ the good line, and F the location of the fault, assumed to be a ground in this figure. The ends of the loop are connected across the terminals of the bridge, so as to form the unknown

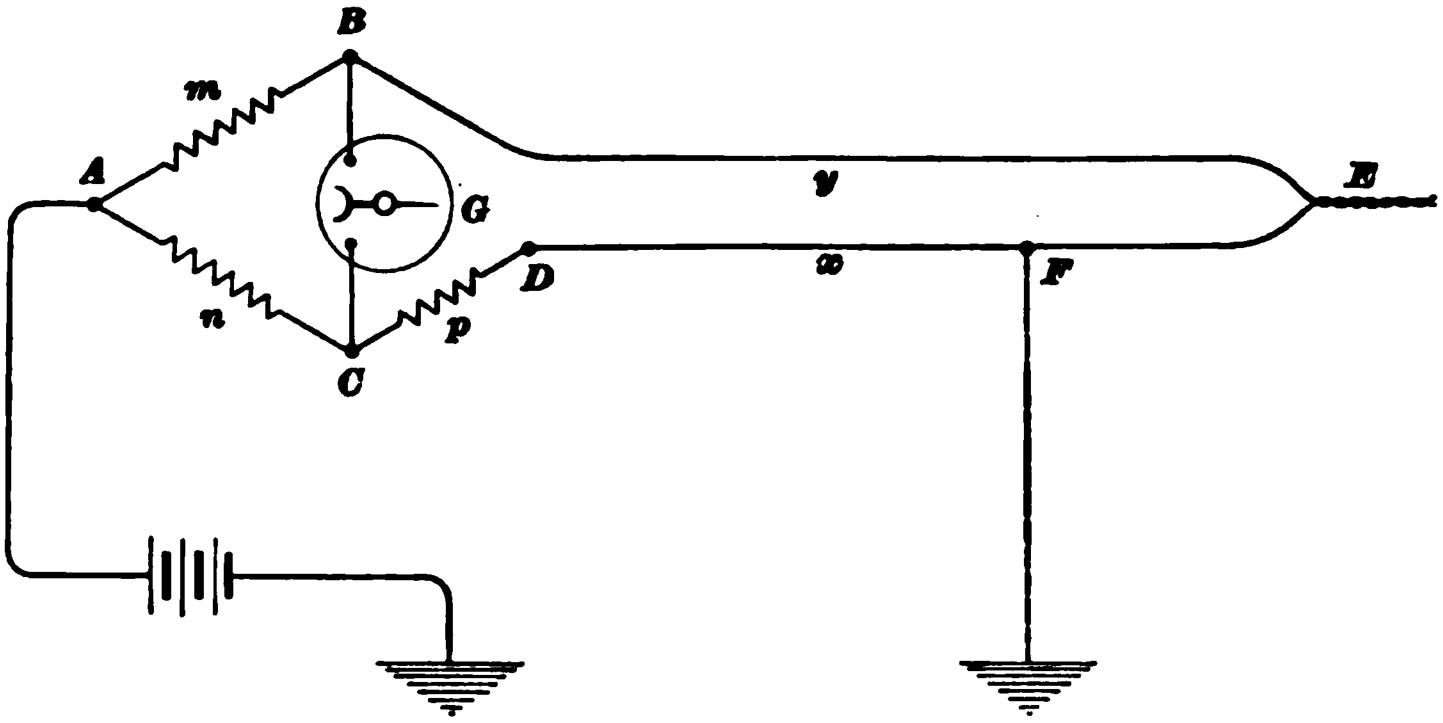


FIG. 94.

resistance or fourth arm of the bridge. The battery is connected between A and D. Balance the bridge and let the resistance of the loop, found by working out the bridge proportion as usual, be R. Then connect one end of the battery to the ground, instead of to D, as shown in Fig. 94. Call y the resistance of the loop from B through E to F, x the resistance from D to F, and R, the total resistance of the loop, is equal to $x + y$. Then, when the bridge is balanced,

$$\frac{m}{n} = \frac{y}{p + x} = \frac{R - x}{p + x};$$

$$m p + m x = n R - n x;$$

$$m x + n x = n R - m p.$$

Hence, $$x = \frac{n R - m p}{m + n}. \qquad \textbf{(16.)}$$

This is entirely independent of the resistance of the fault or of any earth currents that may exist. Having found x, and knowing the resistance of the faulty wire per foot, the distance to the fault is readily calculated. If the faulty line is not grounded but is crossed with another, then the battery should be connected to the wire with which the faulty wire is crossed, and not grounded, as shown in the figure.

EXAMPLE.—A ground occurs on one conductor of a cable 10,000 feet long, composed of three No. 14 B. & S. gauge insulated copper conductors. At the distant end, the grounded conductor was joined to one good conductor On testing, the bridge was balanced with the following resistances $m = 10$ ohms, $n = 1,000$ ohms, and $p = 4,642$ ohms. One good wire was used to complete the loop. Where is the ground, the resistance per thousand feet of the conductor being 2.521 ohms at the temperature of the test?

SOLUTION.— $R = 2 \times 10 \times 2.521 = 50.42$ ohms.

$$x = \frac{1,000 \times 50.42 - 10 \times 4,642}{10 + 1,000} = 3.9604 \text{ ohms.}$$

Distance from testing station $= \frac{3.9604}{2.521} \times 1,000 = 1,570.9$ ft. Ans.

301. Murray Loop Method.—This method is quite similar to the preceding and there is little choice between them. Sometimes one may be more convenient than the

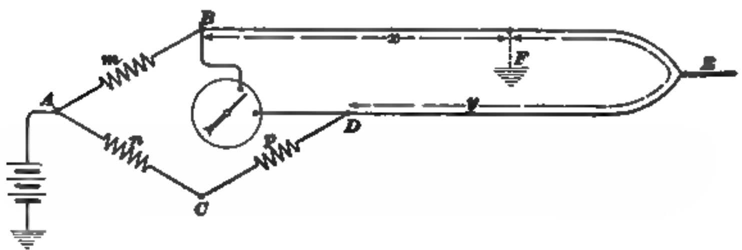


FIG. 95.

other. First have the distant ends of the available good and bad wires joined together. Then connect the loop so formed as in Fig. 93, for the Varley loop test, and measure the resistance of the loop. Let this resistance be R. Then

connect the loop and battery as in Fig. 95, thus having really only two adjustable arms, because $A\ C$ and $C\ D$ form only one arm now. F is now the junction between the arms x and y. When the bridge is balanced, we have

$$\frac{m}{n+p} = \frac{x}{y}.$$

But, $$x + y = R.$$

Solving these two equations for x, the resistance of the line wire to the fault, we get

$$x = \frac{m\,R}{m+n+p}. \qquad \textbf{(17.)}$$

A test made by this method gives a result that is independent of the resistance at the fault.

EXAMPLE.—In order to locate a ground on one conductor in a cable, the Murray loop method was used. At the distant end of the cable, the bad wire was joined to a good wire and the resistance of the loop so formed was measured by the Wheatstone bridge and found to be 63.44 ohms. One end of the galvanometer was then disconnected from the junction C between the arms n and p (see Fig. 95), and was joined instead to the point D between the arm p and the good wire. The bridge was then balanced and it was found that there was 1,000 ohms in the arm m, 1,000 in n, and 282 in p. Each conductor in the cable consisted of one No. 12 B. & S. gauge insulated copper wire, having a resistance of 1.586 ohms per 1,000 feet at the temperature of the test. What was the distance in feet from the testing station to the fault?

SOLUTION.—By substituting in formula **17**, in which $R = 63.44$ ohms, $m = 1{,}000$, $n = 1{,}000$, and $p = 282$, we get as the resistance along the bad wire to the fault,

$$x = \frac{1{,}000 \times 63.44}{1{,}000 + 1{,}000 + 282} = 27.80.$$

Then, the distance to the fault in feet from the testing station is

$$\frac{27.80 \times 1{,}000}{1.586} = 17{,}528 \text{ ft., or } 3.32 \text{ mi.} \quad \text{Ans.}$$

302. Allen Loop Test.—Allen's modification of Murray's loop test gives a very simple and quick method of testing where the resistance of the loop is not already known.

The loop $B\ E\ D$ is connected to the bridge, as shown in Fig. 90, and a balance obtained. Then,

$$\frac{m+y}{n}=\frac{x}{p}.$$

Now, reverse the connections of the loop with the bridge,

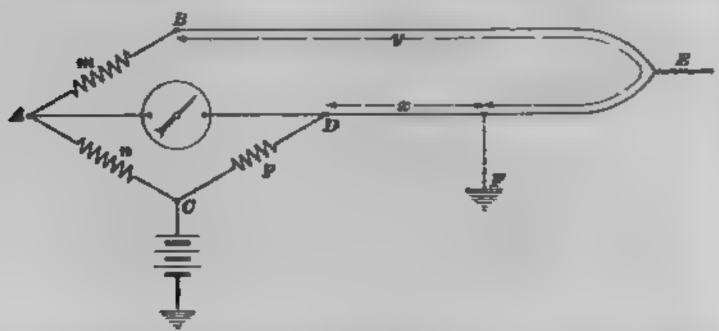


FIG. 90.

joining the bad wire to B and the good wire to D. Obtain a new balance on the bridge, then

$$\frac{m'+x}{n'}=\frac{y}{p'}.$$

Solving these two equations for x, we get

$$x=\frac{p(m\,n'+p'\,m')}{n\,n'-p\,p'}. \qquad \textbf{(18.)}$$

This formula simplifies when m, m', n, and n' are multiples of 10, as they usually are, in practice. A measurement made by the Allen loop test is independent of the resistance at the fault.

LOCATING CROSSES.

303. Where the two crossed wires run along parallel and have the same resistance per mile, it is rather a simple matter to locate a cross. Where such is not the case, the resistance of each wire per mile must often be considered.

304. Resistance at the Cross Negligible.—It is first necessary to determine if the resistance at the cross is negligible. This may be done as follows: Connect the lines

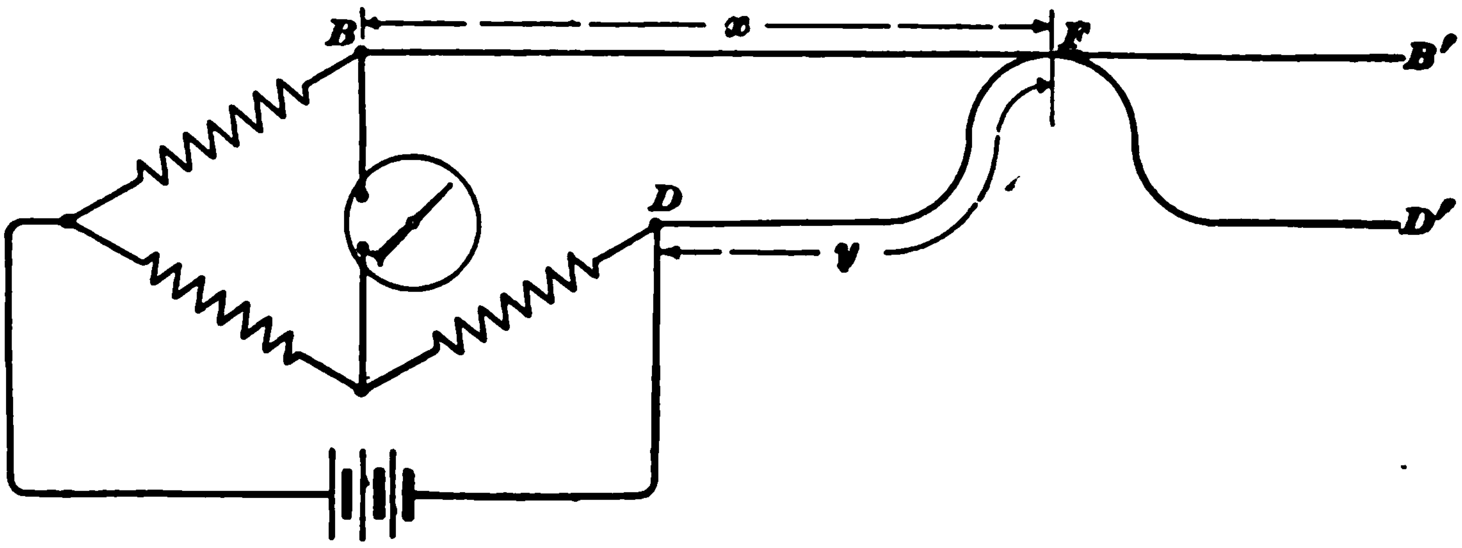


FIG. 97.

with a Wheatstone bridge as shown in Fig. 97, so as to measure the resistance from B to D through the cross F. Call this a.

Then, $$x + y = a.$$

Now have the wires connected together at the nearest station beyond the cross and again measure the resistance. Call this b. If b is only a little less than a, then the resistance of the cross is probably negligible, but not necessarily perfectly negligible. For if the cross is near the testing station and the resistance of the line wires to the next station where the lines are intentionally connected together is very high, then the second measurement b may be but little less than the first measurement a, in spite of the fact that the resistance of the cross is not perfectly negligible. If the resistance of the cross is negligible, then, if the two wires are of the same size and material and run along parallel the whole distance from the testing station to the cross, the distance w to the fault in miles is given by the following formula:

$$w = \frac{a}{2s}, \qquad \textbf{(19.)}$$

in which s is the resistance per mile along one of the wires.

305. Resistance of the Two Line Wires per Unit Length Not Equal.—If the wires are still parallel with each other, but the resistance of one is m ohms per mile and the other n ohms per mile, then the formula becomes

$$w = \frac{a}{m + n}. \qquad \textbf{(20.)}$$

RESISTANCE OF THE CROSS NOT NEGLIGIBLE BUT CONSTANT.

306. Varley Loop Method.—First insulate the distant ends of the two crossed wires. Then connect as shown in Fig. 98, and measure the resistance from D to B through

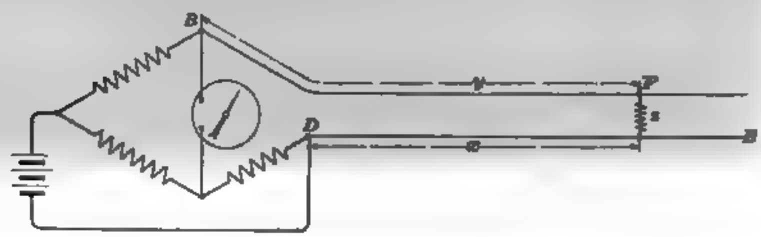


FIG. 98.

the cross at F. Let the resistance of the cross be z ohms, and the resistance found by balancing the bridge be R ohms Then,

$$R = x + y + z. \qquad (1.)$$

Now ground either wire, say $D\,E$, anywhere beyond the cross, as at G, and connect as shown in Fig. 99. When the bridge is again balanced, we have

$$\frac{m}{n} = \frac{y + z}{p + x}. \qquad (2.)$$

From equations (1) and (2), we get the formula

$$x = \frac{n\,R - m\,p}{m + n},$$

which is exactly the same as formula **16.**

Then, by dividing x by the resistance of the wire $D\,E$ per unit length, we have the distance from D to the fault along the wire $D\,E$. The resistance of the cross z eliminates and the method is accurate, provided the resistance z has remained the same during both measurements.

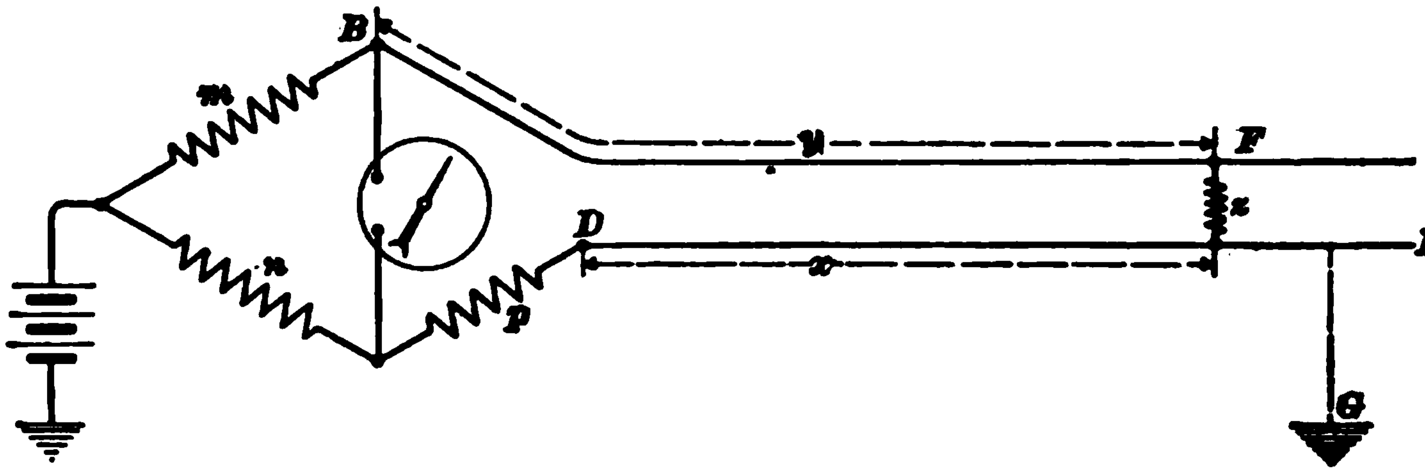


FIG. 99.

307. Method Requiring Three Measurements.—Measure, as in the preceding method, the resistance from B to D through the cross whose resistance we will call z ohms, connecting the bridge as shown in Fig. 98. Let the resistance so measured be a; then,

$$x + z + y = a.$$

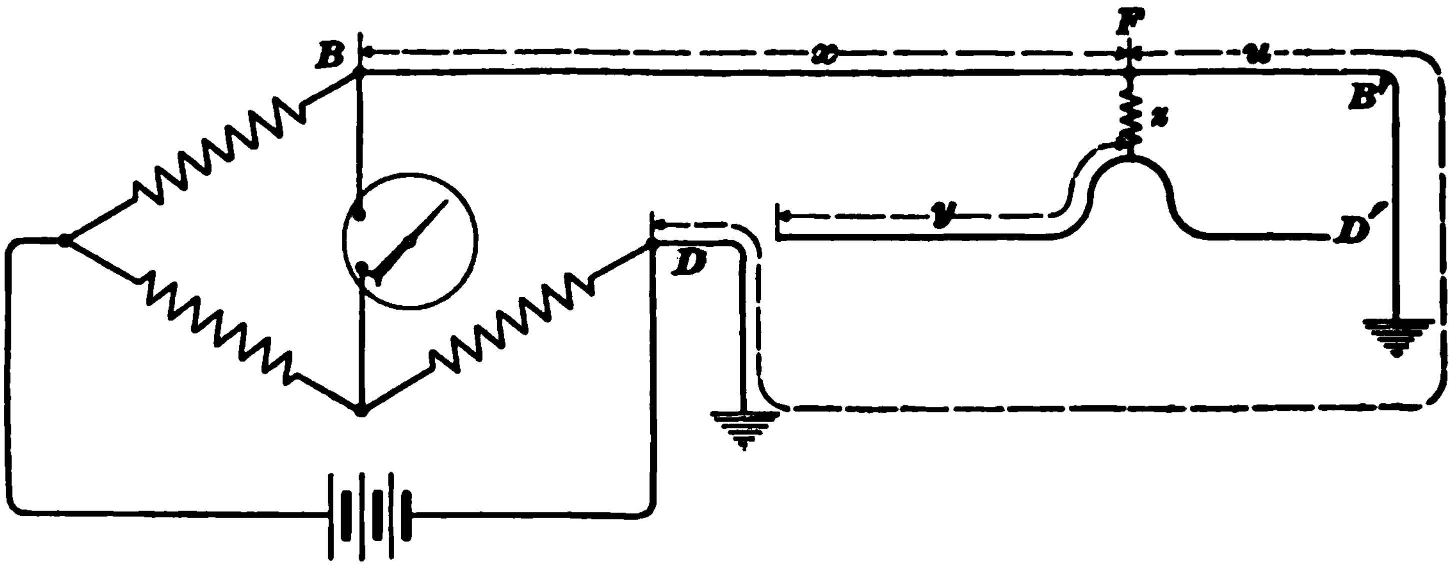


FIG. 100.

Now measure the resistance of the line $B\,B'$ by having the distant end B' grounded, and the ends of $D\,D'$ open as shown in Fig. 100. Let this resistance be b; then,

$$x + u = b.$$

Finally, measure the resistance through y, z, and u, by

connecting the bridge as shown in Fig. 101. Let this resistance be c; then,

$$y + z + u = c.$$

Subtracting the last equation from the sum of the first two equations, we get

$$a + b - c = 2\,x.$$

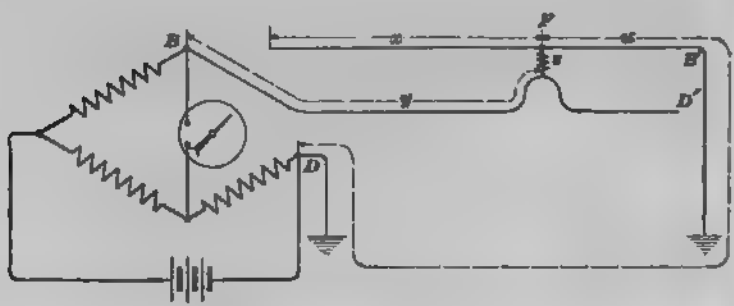


FIG. 101.

Hence the resistance x from the testing station to the fault is given by the following formula:

$$x = \frac{a + b - c}{2}. \qquad \textbf{(21.)}$$

Dividing x by the resistance of the wire x per mile gives the distance in miles to the cross F. It will be noticed that the resistance of the cross z eliminates, so that if z remained constant during the second and third measurements, the formula is accurate and independent of the value of z.

308. Resistance of Cross Neither Negligible Nor Constant.—A method will now be given in which the resistance of the cross is eliminated, whether constant or variable, and the test requires, moreover, only two resistance measurements. However, the ordinary bridge connections have to be slightly modified, which is an objection.

First, connect up as shown in Fig. 100, and measure the resistance of the line $B B'$, including the ground-return path. Let this be a; then

$$x + u = a. \qquad (1.)$$

Then connect the bridge as shown in Fig. 102, using only two arms p and n of the bridge; the third arm m, being on open circuit, is not used. The galvanometer, instead of being connected to the end of the arm m, is connected to the end of the wire D. Thus, $B F$ forms the third arm and $F B' C$ the fourth arm of the bridge. The resistance of the cross z and that portion y of the line $D D'$ is included in the bridge or galvanometer circuit, and, therefore, this resistance z and y will not enter into the result for the

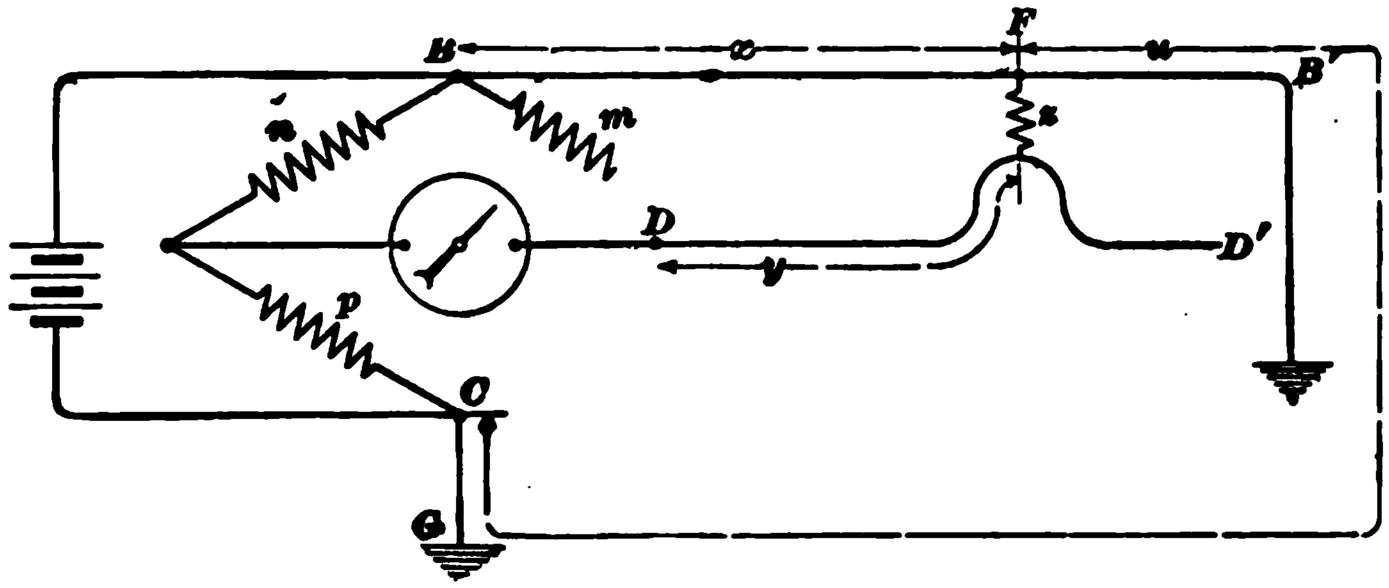


FIG. 102.

same reason that the resistance of the galvanometer never does in measurements made with the Wheatstone bridge method. Hence, the resistance of the cross does not enter into the measurement, and, furthermore, the final formula is entirely independent of this resistance whether it is constant or not. The resistance u, from F through B' and back through the ground to G, forms the fourth arm of the bridge. From the well-known principle of the bridge, after adjusting it until there is no deflection, we have

$$\frac{n}{p} = \frac{x}{u}$$

Solving equations (1) and (2) for x, we obtain the following formula for the resistance along the wire $B\,B'$ to the cross:

$$x = \frac{n\,a}{p + n}. \qquad \textbf{(22.)}$$

Finally, by dividing x by the resistance of the line $B\,B'$ per mile, we get the distance in miles from B to the cross F.

If more convenient to do so, the end B of the wire may be joined to the end of the arm m. In this case x in equation (2) must be changed to $m + x$ and we get the following formula for x:

$$x = \frac{n\,a - p\,m}{p + n}. \qquad \textbf{(23.)}$$

TANGENT GALVANOMETER.

309. The principle and the method of using the **tangent galvanometer** have been given in *Electrical Measurements*, and it is only necessary to give here a short description of the particular form of the instrument that is most commonly used for telegraph testing. Tangent galvanometers are very rapidly going out of use. Ammeters and voltmeters of the Weston type are very much more satisfactory and can be obtained sufficiently sensitive and accurate for all practical work.

310. The tangent galvanometer known as the *Western Union Standard* is shown in Fig. 103 (a). On the base at the right are the terminals of three resistances, arranged so any one, or all three, can be short-circuited by brass plugs. A diagram of the arrangement of the coils and resistances is shown in Fig. 103 (b). These resistance coils of 5,000, 500, and 10 ohms, respectively, are often very convenient when making a measurement. For instance, if the deflection is too small and it is not convenient or possible to increase the electromotive force, the deflection may be increased by inserting the plugs so as to short-circuit one or more of the

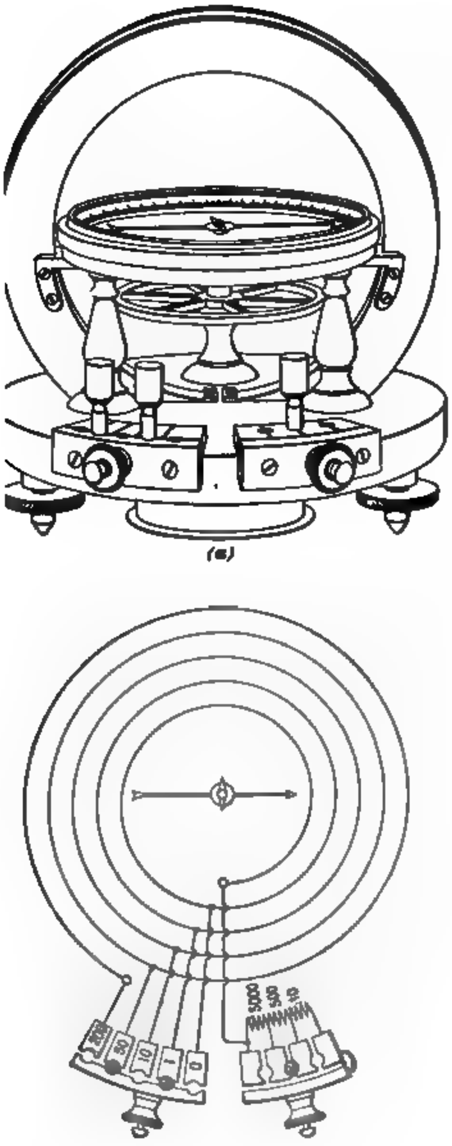


FIG. 103.

resistance coils on the right. Conversely, if the deflection is too large, it may be reduced by removing one or more of the short-circuiting plugs.

311. Dial Graduated in Tangents.—In some tangent galvanometers in use, the dial is divided on one side in degrees, but on the other side t' figures correspona to the tangent of the angle of deflection. This is more convenient, as it avoids the necessity of looking up the tangent in a table corresponding to the deflection of the pointer in degrees, but the scale is not apt to be so accurate. The student has been furnished with a table of tangents, suitable for use with the tangent galvanometer, in the volume of *Tables and Formulas*.

312. These tangent galvanometers may be obtained with a needle suspended by a silk fiber. This makes the instrument more sensitive, but also more delicate and liable to injury. The tangent galvanometer is ordinarily used for measuring the strength of currents, internal resistance, electromotive force, and condition of cells.

ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE OF BATTERIES.

313. There are a number of methods for accurately determining the internal resistance and electromotive force of cells. Probably the most accurate methods for determining electromotive forces are those requiring Standard Clark cells, accurate resistances, or condensers. These are suitable only for laboratories, however. For practical measurements the half-tangent or half-deflection and Mance's bridge methods for internal resistance, and the volt and ammeter method for both internal resistance and electromotive force, are the most suitable

314. Half-Tangent Method.—For the half-tangent method, an adjustable resistance box and a tangent galvanometer are generally used. However, it may be made with an ordinary Wheatstone bridge set, and a much more convenient way is to use a milliammeter in place of the tangent galvanometer. These two modifications will be explained presently.

315. In series with the cell or battery whose internal resistance is desired, connect an adjustable known resistance and the tangent galvanometer. Use such a coil of the galvanometer or arrange the adjustable resistance so that a deflection between 60° and 80° is obtained It is best in this case to use as little of the adjustable resistance as possible. With cells like the gravity having an appreciable

internal resistance, no resistance is necessary at all external to the cell. If the deflection is too large, it is preferable to use a galvanometer coil having fewer turns. Suppose there is a small resistance a external to the cell. This must include the galvanometer resistance unless the latter is small enough to be neglected. Note the galvanometer deflection in degrees and from a table of natural tangents obtain the tangent corresponding to this angular deflection. Divide this tangent in half and from the same table obtain the degrees corresponding to this half-tangent. Then increase the known adjustable resistance until the deflection is reduced to the degree obtained from the table. Let the known total external resistance now be c ohms. Since the tangent of the second deflection is half the tangent of the first deflection, it is evident that the current has been reduced one-half and the total resistance must, therefore, have been increased to double its first value. Hence, if B is the internal resistance of the cell or battery, then

$$2(B + a) = B + c.$$

From which we get

$$B = c - 2a. \qquad \textbf{(24.)}$$

Evidently, if no external resistance a was used when the first deflection was obtained, B would be equal to c.

316. Half-Deflection Method Using an Ammeter.—An ammeter or milliammeter of suitable range can be used in place of the tangent galvanometer, and it is much more convenient. All that is necessary is to adjust the resistances, so that one reading on the scale is just one-half the other. The reading gives the current directly. The internal resistance is worked out in the same manner, using formula **24.**

317. Half-Deflection Method Using a Bridge Set.—The bridge in this case is used as a simple adjustable resistance. The proper connections are shown in Fig. 104.

The bridge galvanometer G must be shunted by a low resistance S, consisting of a few ohms, so that the joint resistance of the galvanometer and shunt may be negligible in comparison with that of the battery, and, furthermore, it is usually desirable to thus reduce the sensitiveness of the

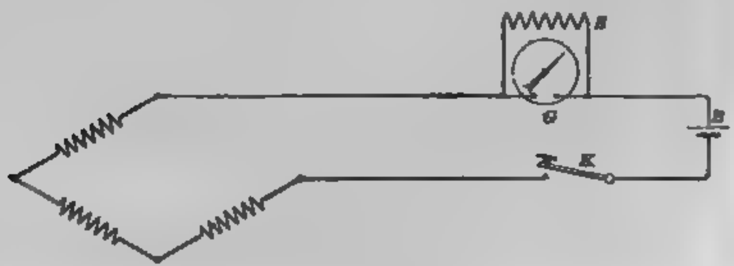


FIG. 104.

galvanometer. Obtain a convenient deflection with any resistance unplugged in the box and note down this resistance a and the deflection of the galvanometer. Then increase the resistance in the box until the deflection is reduced one-half. Note this resistance c. The internal resistance of the cell or battery is given by formula **24.**

EXAMPLE.—A gravity cell, connected in series with a tangent galvanometer and a resistance of .3 ohm, gave a deflection of 65°. The resistance of the galvanometer and all connecting wires was .1 ohm. The tangent of 65° was found in a table of natural tangents to be 2.14451 The angle, having a tangent of ½ (2.1451) = 1.07225, was found in the same table to be very nearly 45°. It was found necessary to add an extra resistance of 3 ohms in series with the cell and galvanometer in order to reduce the deflection from 65° to 46°. What was the internal resistance of the cell ?

SOLUTION.—By formula **24**, the internal resistance $B = c - 2a$, in which $c = 3 + .3 + .1 = 3.4$ and $a = .3 + .1 = .4$. Hence, $B = 3.4 - .8 = 2.6$ ohms. Ans.

318. Mance's Bridge Method.—The connections for this method of measuring the internal resistance of the battery B is shown in Fig. 105. The battery B is connected

in the arm of the bridge where the unknown resistance is usually connected, and the junction points A and D, between which the battery is usually connected, are joined together through the key K, which is normally open. It is usually necessary to shunt the galvanometer by a resistance S in order to reduce its sensitiveness so that the deflection will remain on the scale. The key K_1 remains closed normally in order to protect the galvanometer. When the connections are made, cautiously depress the key K_1 and adjust the shunt and various resistances until a convenient deflection is obtained. Then depress the key K, which will probably

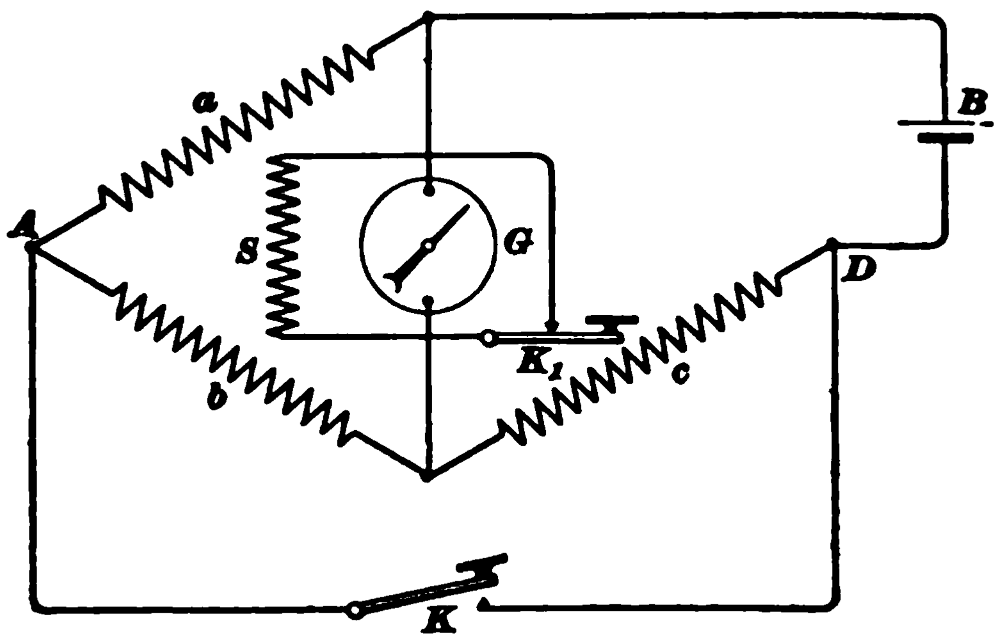


FIG. 105.

alter the deflection. A balance is obtained when the resistance arms have been so adjusted that *no change* in the galvanometer deflection occurs on opening or closing the key K, the other key K_1 being held open all the time. The resistance of the battery is then found by the ordinary bridge proportion; that is, the internal resistance of $B = \frac{c\,a}{b}$.

If the internal resistance of the battery is small, it is convenient to insert a resistance in series with the battery. This resistance must afterwards be subtracted from the resistance obtained from the bridge. The advantage of Mance's bridge method is that the deflection does not enter into the result.

319. Volt-and-Ammeter Method.—By this method both the internal resistance and the electromotive force of the cell are obtained simultaneously from the same measurements, and, moreover, the measurements may be made when the cell or battery is generating the same current that it would when actually working on a telegraph line or local circuit. It, therefore, may be made to give the internal resistance under normal working conditions. The connections for this method are shown in Fig. 106, in which A is an ammeter and V a voltmeter of suitable range, R a resistance of such a value that the battery B to be tested will furnish its normal amount of current, and K a switch or key. Let B be the internal resistance of the battery, C the current measured by the ammeter A, E the electromotive force of the cell when the key K is open, and V the difference of potential at the terminals of the cell when C amperes are flowing through R on account of the key K being closed. E and V are measured by the voltmeter. The resistance of the voltmeter should be at least a thousand times that of the battery, or, better, several thousand times. The ammeter and resistance R must be low enough to allow the battery to work at its normal rate of output, and it is better that the ammeter resistance should be very low.

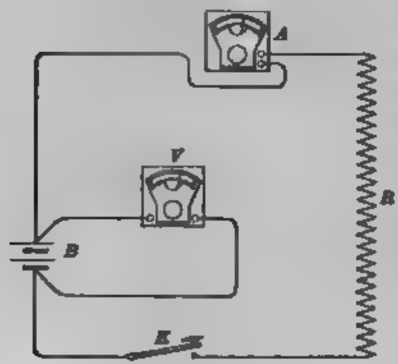


FIG. 106.

With the key K open, read the voltmeter. This will be E, the electromotive force of the battery when practically no current is flowing, that is, when the battery is practically on open circuit. Then close the key K and immediately read simultaneously, or as nearly so as possible, both the ammeter and the voltmeter. These two readings give the current C and the difference of potential V at the battery

terminals when C amperes are flowing through the circuit. Then, $E - V$ is the drop or fall of potential necessary to drive the current C through the battery against the internal resistance B. But this fall of potential by Ohm's law $= B \times C$; hence,

$$B = \frac{E - V}{C}. \qquad \textbf{(25.)}$$

This is the internal resistance at an output of C amperes. At another rate it may be different.

If the total resistance R external to the battery is known, the ammeter will not be necessary, for the current C is equal to $\frac{V}{R}$ and can, therefore, be calculated.

320. To Determine Condition of Cells.—To determine merely if a cell or battery having an appreciable internal resistance, such as a gravity cell, is above a minimum standard condition, the following method is often used. As already stated, the copper band on the tangent galvanometer has no appreciable resistance; hence, if this coil is connected directly in series with a battery, the current is limited practically by the internal resistance of the battery.

Determine, once for all, the minimum deflection that a cell in good working condition will give. Then, if the deflection falls below this with another cell or a whole battery, something is wrong with the cell or with one or more of the cells in the battery. No more current will be obtained from a whole set of cells connected in series than from one cell where the external resistance is negligible, because the total resistance of the circuit varies directly as the number of cells connected in series, and, hence, the total resistance varies directly as the total electromotive force. This was fully explained in *Telegraphy*, Part 1, under the heading "Small External Resistance."

321. When the deflection from a whole battery falls below the standard, a careful inspection may show one or

more defective cells. If not, a defective cell may be located by testing each cell separately. If there is no especially bad cell in the set, then the condition of the battery as a whole is poor.

This method cannot, of course, be used with batteries or cells that have little or no internal resistance. A storage battery, if tested in this way, would probably ruin not only itself but also the galvanometer, on account of the large current that would flow, since the total resistance of the circuit is so small.

322. Bunnell Battery Gauge.—This gauge, shown in Fig. 107, consists of a coil of wire and an armature to which the pointer is attached. It is very convenient for determining the condition of from one to five ordinary cells. A good Leclanché cell will indicate about 9°; standard dry battery 14°; Lockwood American District (blue vitriol) 6°; crowfoot, Western Union form, 8°.

Fig. 107

This gauge can be used standing upright on the table or desk, or suspended by the chain and ring, which brings the needle to zero when no current is passing through the instrument. On account of their normal position being upright, these gauges may be used as permanent circuit indicators for fire-alarm, burglar-alarm, and district-telegraph lines. The action of the needle is "dead beat." It moves to and remains, without oscillation, at whatever indication the current calls for. There are two silk-covered conducting cords provided with tips,

made so as to enter any ordinary binding post, and, being square, can be also firmly held by the English form of binding post. These tips have a spring clamp by which they can firmly grip naked wire (up to No. 16) at any exposed point.

WIRELESS TELEGRAPH.

EARLY INVESTIGATORS AND METHODS.

323. The idea of telegraphing between two stations that are not directly connected by at least one wire is quite old. Morse, Lindsay, Willoughby Smith, and others proposed and some of them actually did telegraph across a body of water by running a wire for some distance parallel to the shore on either side and then connecting each end of each wire to a plate submerged in the water; one plate on either side was directly opposite a corresponding plate on the other side of the stream. If the wires parallel to the shore are long enough and the stream not too broad, the electric current will flow across the stream at one point from plate to plate, through the wire on the opposite side, and finally across the stream at the other point and into the wire on the first side. Enough of the current will follow this path, in preference to flowing along the stream, to operate a relay. The ability to telegraph in this manner is due to the fact that the resistance of the body of water across the stream from plate to plate is less than the resistance along the stream between the two plates on the same side. To be sure, more or less current will flow from one plate to another on the same side of the stream. It is invariably better, where it can be done, to connect the two telegraph stations by an overhead wire or submerged cable. This is sometimes called the *conduction method*. Willoughby Smith put such a system in operation in 1885, between the shore and a lighthouse, a distance of 60 yards, and it was successfully used for a number of years.

324. Another very different method has been proposed and was put in operation by Mr. W. H. Pierce, who has worked more or less on the subject since 1882. The success of this method is due to electrostatic and electromagnetic effects and to conduction through the earth. The best results were obtained by using two long parallel wires grounded at both ends. One wire, with the earth return, forms a long rectangular coil and acts as a primary coil; and the other with an earth return, as the secondary coil of an induction coil, the two coils being separated by the distance across which it is expected to telegraph. There may, in addition to electromagnetic induction, be electrostatic induction between the two long parallel wires and conduction through the earth between the opposite ground plates at the two ends. An alternating or rapidly interrupted current is used in the primary or sending side, and an ordinary key may be used to make Morse signals by interrupting the rapidly pulsating or alternating current. A telephone receiver is used in the secondary circuit to read the signals. A sound, due to the alternating current that causes the diaphragm of the receiver to vibrate, corresponds to dots and dashes, and silence corresponds to spaces. The length of the two parallel wires should be at least equal to the distance separating the two wires. Telegraphic and telephonic communications have been successfully carried on by this method between stations from 3 to 5 miles apart.

325. The most successful method for telegraphing through space without a connecting wire has been perfected by Guglielmo Marconi, an Italian. His method depends on the coherer invented by Branly (about 1890) and also on discoveries made by Lodge and Righi. To Maxwell and Hertz is due the credit of predicting and demonstrating, respectively, the fact that electromagnetic waves are propagated through space with the velocity of light. Such waves are frequently called **Hertzian waves.** These waves are identical in some respects to light waves, but have different frequencies and wave lengths and other different properties.

For instance, while wood and many other substances are not transparent to light waves, they are transparent to electromagnetic waves. Most metals, however, are opaque to almost all waves. Our optical nerves are capable of detecting light waves but cannot detect electromagnetic waves. Electromagnetic waves range from $2\frac{1}{2}$ inches in length to about 18 miles and have a frequency from 480,000,000 to 10,000 periods per second, respectively; whereas the length of light waves range from 165 millionths of an inch to 272 millionths of an inch and have a frequency from 740 trillion to 434 trillion periods per second, respectively. A coherer, which will be described presently, is insensible to light waves, but will readily detect some electromagnetic waves.

326. Calzecchi Onesti, an Italian, was about the first (in 1884) to discover the sensibility of filings to Hertzian waves. He found that metallic filings in a loose state offered an appreciable resistance, but when exposed to Hertzian waves the resistance decreased enormously, but that on shaking them up the resistance was increased to its original value.

Professor E. Branly, of Paris, developed the discovery of Calzecchi Onesti, and made about the first instrument, now called a coherer, publishing the results of his investigation in 1891.

Professor O. J. Lodge, of England, was probably the first to call Branly's instrument a coherer and to use it in 1893 for detecting electromagnetic waves at a distance (about 125 feet) from the generator and to tap the tube by means of a clock movement in order to restore the resistance of the filings to their normal condition.

Professor Popoff, of Russia, was the first to automatically cause the hammer of a sounder or bell to restore the coherer to its natural state, or to *decohere* it, as it is usually called. He had also used vertical wires in lightning-discharge investigations.

tapping of the tube does not restore it to its normal high resistance as long as sufficiently intense waves from *a b* strike it, but the first tap after the waves cease restores it to its normal high resistance and hence the relay opens and the tapping ceases. *R* is rather a high resistance and sensitive relay, and *L B* a local battery of one cell.

330. Explanation of the Action of a Coherer.—The following explanation of the action between the filings in a coherer, which is given by Professor Lodge in his book "Signaling Through Space Without Wires," is the one generally accepted

"Suppose there are two fairly clean pieces of metal in light contact connected in series with a single voltaic cell; a film of what may be called oxide intervenes between the surfaces so that only an insignificant current is allowed to pass, because a volt or two is insufficient to break down the insulating film. If the film is not permitted to conduct at all, it is not very sensitive; the most sensitive condition is attained when an infinitesimal current passes, strong enough to just show on a moderately sensitive galvanometer. Now let the slightest surging occur, say by reason of a sphere being charged and discharged at a distance of 40 yards; the film at once breaks down, perhaps not completely—that is a question of intensity—but permanently. Apparently more molecules get within range of each other and a momentary wave seems to weld them together. It is a singular variety of electrical welding. A stronger wave enables more molecules to hold on and the change in resistance seems to be proportional to the energy of the electric radiation from a source of given frequency. It is to be especially noted that the battery current is not intended to effect the cohesion, only to show that it has taken place. The battery can be applied after the spark has taken place and the resistance will be found to have changed as much as if the battery had been on all the time. The cohesion electrically caused can be mechanically destroyed. Ground vibrations or any other feeble mechanical disturbances such as scratches or

taps are well adapted to restore the contact to its original high resistance and sensitive condition. The more feeble the electrical disturbance, the slighter is the corresponding mechanical jar needed for restoration."

331. Metals Opaque to Hertzian Waves.—Waves cannot get at a coherer that is completely shut up in a metallic box, but if wires are led to it from outside, the waves seem to run along the wires into the box and the coherer is nearly but not quite as sensitive to the external waves as if no enclosing box had been used. To screen it perfectly, according to Professor Lodge, it is necessary to have no opening of any kind in the box. Even the joints should be soldered. A lid, if securely clamped, using pads of tin-foil to secure perfect joints, may suffice. The inside of the box is then said to be electrically dark. Even a single wire protruding from the box, although not connected to anything at either end, is sufficient, provided it is insulated from the box itself and does not, therefore, completely fill the hole with metal, to allow the waves to run along it into the box. A small round hole, however, seems to let in but few waves provided no insulated wire protrudes, but a long narrow chink or crack will let in a large number of waves.

MARCONI SYSTEM.

332. The arrangement of transmitting and receiving apparatus patented by Marconi and said to be used by him is shown in Fig. 109. A long vertical wire ends in a plug P that may be inserted in the receptacle m for transmitting and in the receptacle n for receiving.

333. Transmitting Apparatus.—The essential part of the transmitting apparatus is an induction, or *Ruhmkorff*, coil, as it is commonly called. The primary winding p and the secondary winding s of the Ruhmkorff coil are both wound upon the same iron core, which is here represented, merely for the sake of clearness, as lying between the two

coils p and s. The current may be rapidly interrupted by almost any ordinary form of interrupter and a condenser C_1 must be connected across the break $c\,d$. The condenser reduces the sparking between c and d and also improves the

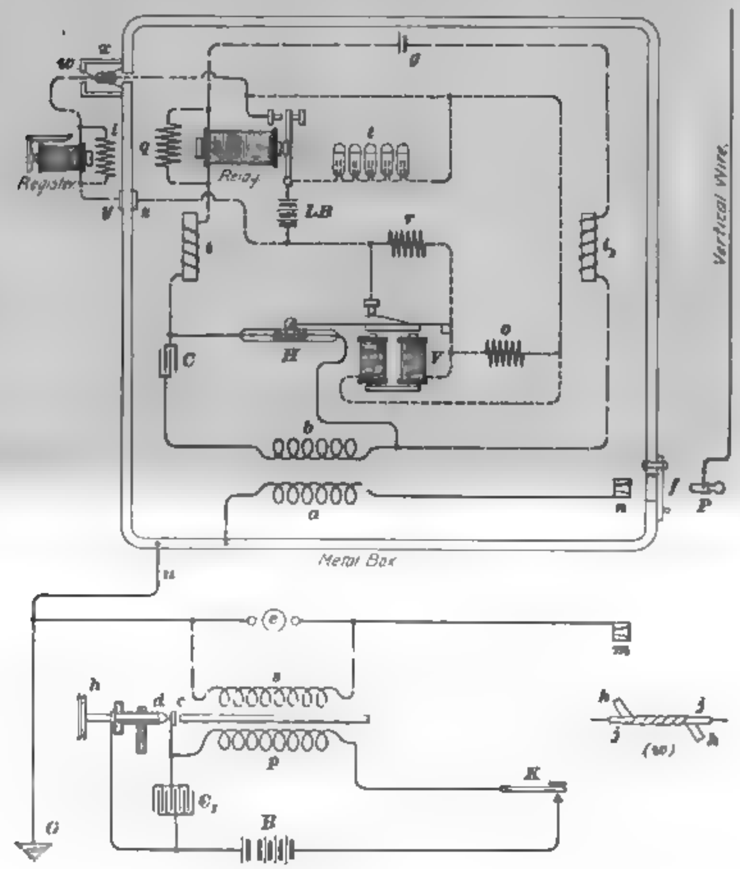


FIG. 109.

action of the coil by causing a more sudden interruption of the current that flows from the battery B through the primary p. Both d and c, where they come in contact with each other, are tipped with platinum to better resist corrosion and fusion. Marconi says he found it advantageous

to rapidly revolve the contact *d* by means of an electric motor of some kind geared to the wheel *h*. By this means the platinum contact surfaces on *d* and *c* are kept smooth and any tendency to stick is removed and they also last longer.

When the key *K* is closed, a constant stream of sparks will pass between the large center sphere *e* and the two smaller spheres, one on each side. The total air gap usually varies from 1 to 2 inches, but the coil must be powerful enough to give an 8- or 10-inch spark. One of these small spheres is grounded and the other connected to a long vertical wire.

The current in the oscillator (to be defined presently) surges back and forth between 100,000,000 and 200,000,000 times per second; each time it does so it charges or discharges the long vertical wire. The charging and discharging currents flow up and down the vertical wire and consequently produce electromagnetic waves that are projected out into space, as horizontal circular waves, from every part of the vertical wire. Furthermore, on account of the static disturbances that are produced in the surrounding space between the vertical wire and the surface of the earth due to the electrostatic capacity of the vertical wire, it is probable that so-called electric waves, which vibrate up and down in vertical planes, are also projected out into space.

Since these waves spread out through space in all directions, it is evident that another vertical wire, if not too far distant, will be cut by some of them. The waves that cut the second vertical wire seem to set up oscillating currents that follow it down to the earth.

334. By means of the key *K*, the current flowing in the primary coil may be broken up into ordinary Morse signals. This will cause waves to be projected into space corresponding to the Morse code. To be sure, each dot consists of millions of waves, but all waves cease when the key is opened. The key *K* used by Marconi when in this country was not an ordinary telegraphic key in the strictest sense, although it was somewhat similar. It had a longer lever (about 14 to 18 inches) pivoted at about its middle, but

instead of a finger button there was a handle extending upwards about 3 inches. The key was moved up and down over a wide gap in order to break the spark in the primary circuit when it was opened. This accounts for the fact that a speed of 12 or 15 words a minute seems to be about the best so far attained, while 10 words is a good average speed

335. Other things being equal, the larger the ball *c*, the greater is the distance through which it is possible to communicate. A solid brass ball *c* 4 inches in diameter, giving waves 10 inches in length, has been used by Marconi He is said to now use simply two 1 inch solid brass balls, one connected to each terminal of the secondary coil, in place of the three shown at *c* in this figure, and a spark gap, varying from 1 to 2 inches, for all distances up to 110 miles. The length of the wave generated depends on the relation between the resistance, self-induction, and capacity of the oscillator. By the oscillator is usually meant merely the circuit from the top of the vertical wire through *m c* to the ground *G*. The capacity of the oscillator is varied by varying the size of the balls and the length of the vertical wire.

336. Sometimes metallic wings of sheet metal are attached to the balls on each side of the spark gap. This will alter the wave length, and if the receiver can be made, by the use of similar metallic wings, to respond only to waves of a certain length (within limits), this affords a method for synchronizing or tuning the receiver and transmitter. In other words, although waves of all lengths may reach the receiving apparatus, it will not respond unless certain particular wave lengths are present.

337. Receiving Apparatus.—To prevent the oscillations generated at a station from acting on its own coherer and rapidly destroying the same, Marconi encloses all the receiving apparatus, with the exception of the Morse register, in a metal box, and leads the wire connecting to the register through a coil encased in bands of tin-foil, the

tin-foil being connected to earth. The box is usually made of iron merely because it is the cheapest metal. The metal need be only $\frac{1}{20}$ or $\frac{1}{16}$ inch thick. The hole at f should be securely closed by a metal door when transmitting. To receive, the door is opened and the plug P inserted in the receptacle n. The current waves that slide or follow down the vertical wire pass through the primary winding a of a step-up *induction coil*, or *transformer*, as it may be called, when they pass through the metal of the box and the wire u to the ground G. The secondary b of this coil is connected in series with a condenser C and a coherer H.

338. The **induction coil** or **transformer** a b should be in tune, or *syntony*, as it is called, with the electrical oscillations transmitted, the most appropriate number of turns and the most appropriate size of wire varying with the length of wave. Marconi says in one of his patents that he

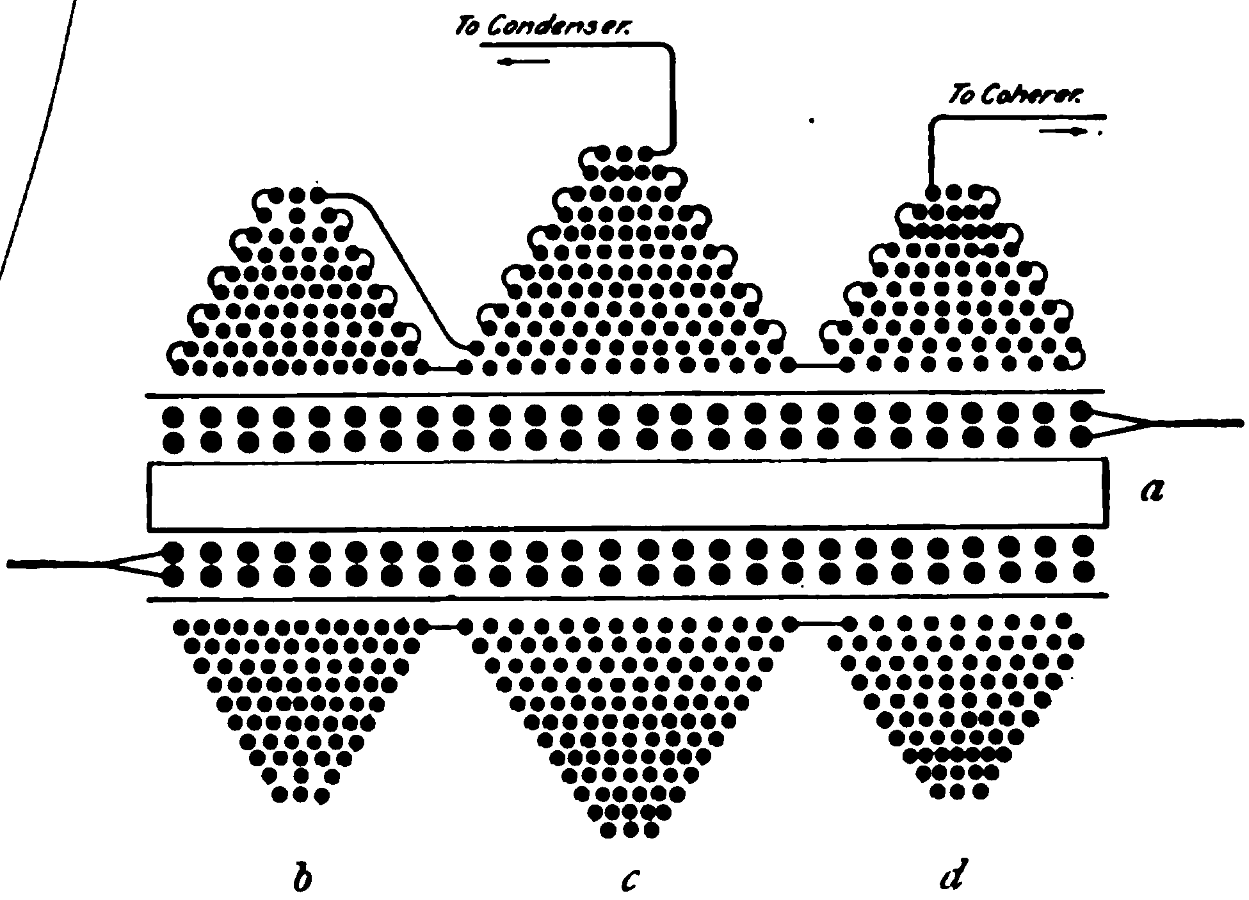


FIG. 110.

obtained the best results (presumably for 10-inch waves) by using a transformer constructed as shown in Fig. 110. The primary a is wound on a glass tube about .37 inch in diameter. The primary winding a consists of two layers in parallel of 160 turns each of No. 38 B. & S., single-silk

covered copper wire. No iron core is used. The secondary is wound in a very peculiar manner, as shown. There is first wound on one layer of 150 turns. The secondary is then divided into three sections *b*, *c*, *d*. The section *b* has nine more layers with 45, 40, 35, 30, 25, 20, 15, 12, and 5 turns in the respective layers; the section *c* has eleven more layers with 40, 39, 37, 35, 33, 29, 25, 21, 15, 10, and 5 turns in the respective layers; section *d* has nine more layers with 45, 40, 35, 30, 25, 20, 15, 17, and 14 turns in the respective layers The same sized wire is used as in the primary These sections must be wound and connected exactly as shown. The coil is .98 inch long.

339. Marconi's Latest Transformer and Connections.—In February, 1901, Marconi received a patent for the following method of connecting his receiving apparatus. The secondary of the transformer is opened in the middle and the inner ends connected to the local circuit, which includes the battery and relay, while the two outer ends are connected to the coherer. It is stated to be advantageous to also connect a condenser across the inner ends of the secondary where the local battery and relay circuit is connected Details of one form of transformer are given as follows: The primary, which is in circuit with the vertical wire, is wound on a non-magnetic core ¼ inch in diameter and consists of 100 turns of No. 27 copper wire, insulated with single silk and coated with paraffin wax. The secondary consists of No. 32 single-silk covered copper wire wound over the primary, commencing at the middle and winding it in the same manner as the primary. Each half of the secondary is wound with a decreasing number of turns, beginning with 77 in the first layer and ending with 3 in the seventeenth, making 500 turns in all. Other forms are also given. These coils are stated to give the best results when the length of the vertical wire at each station is 150 feet.

340. Transformer. — It was natural to attempt to increase the induced electromotive force acting on the

coherer by an induction coil, analogous to those used in telephony. The above manner of constructing a transformer seems to reduce to a minimum the impedance and to realize the maximum induction between the primary and the secondary for these high-frequency currents.

The only explanation offered for winding and connecting the coils in the particular manner stated above is that given by Marconi, who says that it is done to prevent the effects due to electromagnetic induction from being in opposition to those due to electrostatic induction at the ends of the primary coil. The favorable action of the transformer is most marked. According to Marconi, this device increases the range from 30 to 60 per cent.

341. The **condenser** *C*, Fig. 109, is made, by Marconi, of six plates of tin or copper foil 1.48 inches by .98 inch, separated by paraffined paper .006 inch thick. Three alternate plates form one side and the remaining three plates the other side of the condenser. This condenser has a capacity of about $\frac{1}{4}$ microfarad. With this apparatus he used a vertical wire 140 feet long, composed of seven strands of about No. 18 or No. 20 B. & S. copper, the top being about 120 feet above the ground.

342. The **coherer** *H*, which is shown in Fig. 111, is made of a glass tube *a* about 1.5 to 2 inches long and having an internal diameter of $\frac{1}{16}$ or $\frac{1}{12}$ inch. Two silver plugs *p*, *p* about $\frac{1}{5}$ inch long fit quite tightly in the tube and have connected to them

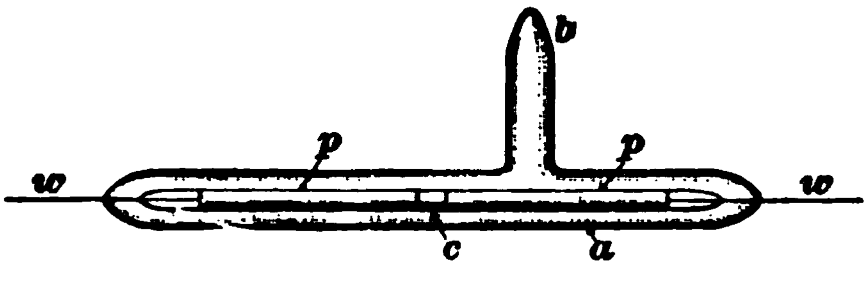


FIG. 111.

the platinum leading-in wires *w*, *w*, which are sealed in the ends of the glass tube. The plugs are separated from each other by about $\frac{1}{30}$ inch, the space *c* between them being only partially filled with a mixture of nickel and silver filings of uniform size and very clean and dry. Researches that have been made for a practical coherer have shown that the filings on electrodes should be made of a metal slightly oxidizable.

The filings should be rather loose and in such a condition that when the tube is tapped, the filings may be seen to move. The filings should be rather coarse, such as produced by a large rough file, which should be frequently washed in hot water, dried, and used warm when making the filings. The mixture should preferably consist of from 90 to 96 per cent. of hard nickel and from 10 to 4 per cent. of hard silver filings. By increasing the proportion of silver, the sensitiveness of the coherer increases, but it is better for ordinary work not to have a tube of too great sensitiveness. The addition of a small quantity of mercury to the filings improves the sensitiveness. There must not be so much mercury as to form a clot or cake in the filings. Sufficient mercury may be obtained by slightly amalgamating the inner surfaces of the silver plugs that are to be in contact with the filings. There should not be more than sufficient mercury to just brighten the surface of the plugs without showing any free globules.

The tube should be sealed and a vacuum, while not essential, is desirable. Care should be taken not to oxidize the filings by too much heat when sealing the tube, and it is better to use a non-oxidizing hydrogen and air flame. A vacuum of about $\frac{1}{1000}$ of an atmosphere is desirable. The tube, if well made, should be sensitive to the waves from the spark produced at the break of an ordinary vibrating bell when working at a distance of not less than 1 or 2 yards from the tube. In order to keep the coherer in good condition, not more than 1 milliampere should ever be allowed to flow through it, even when active. For this reason never more than 1 Leclanché cell, nor over 1.5 volts, should be applied to the terminals of a coherer.

343. Choking Coils.—The coils i and i_1, in Fig. 109, known as **choking coils,** are formed by wrapping a few inches of very thin insulated copper wire around an iron wire about 1.5 inches long.

344. Magnetic Instruments. — An ordinary vibrating bell is used to tap the coherer in order to restore it to its

normal condition when the waves which have been acting upon it cease. The relay connected in the circuit with the coherer should have quite a large resistance, preferably about 1,200 ohms, and the vibrating bell about 1,000 ohms.

Mr. Marconi suppresses, as completely as possible, all parasitic waves originating from contacts made and broken in the receiving apparatus itself and capable of actuating the coherer. To this end he has placed non-inductive shunts around each point where the circuit is broken and around all coils subject to the electromotive force of self-induction; the spools of the relay in particular have been thus shunted. Each one of these non-inductive resistances *l*, *q*, and *o* should have a resistance about four or five times that of the instrument which they shunt.

345. All Contact Points Shunted.—There should also be a smaller non-inductive resistance across all contact points at which a circuit is broken in order to prevent a spark. Such resistances are shown at *r* and *t*. The resistance *t* is preferably made of a series of tubes containing two electrodes and water acidulated with sulphuric acid. The number of these tubes in series should be about 10 where a circuit containing 15 volts is broken, in order to prevent the passage of much current from the local battery. Such cells possess quite an electromotive force, called a *counter electromotive force*, which prevents the flow of a steady current, but allows the high-tension and nearly instantaneous current produced by self-induction upon the opening of the circuit by the relay armature to pass easily through them and so do away with the disturbing sparks that would otherwise be produced at the relay contacts. The vibrator should preferably be arranged to tap the coherer tube underneath in order to prevent the packing or caking of the filings.

346. It is necessary to have the Morse register, which is generally used, on the outside of the box, so that the message may be seen as it is received. One of the wires

from the inside is fastened to the metal box at s and the one on the outside at y; the metal of the box completes the circuit. The other wire w passes through an opening in the box in the following manner: A coil of wire is made containing about 120 turns of about No. 28 B. & S. copper wire. This wire, as shown in the small detached view (w), is insulated by the gutta percha j, which is then covered with the tin-foil k. The tin-foil is electrically connected to the metal box. This method seems to protect the coherer from the oscillations set up by the home transmitter. This coil is usually protected by a metal or wooden casing x.

347. Batteries.—The battery g, the current from which flows through the coherer H and operates the relay, consists of only one cell. The battery $L B$ furnishes the current for operating the vibrating bell V and the Morse register, and it may consist of any desirable number of cells, usually about 12 cells being required. The battery B for operating the Ruhmkorff coil should preferably consist of storage cells or a dynamo, because a steady current of about 6 amperes is required for a coil capable of producing a 10-inch spark.

REMARKS CONCERNING APPARATUS.

348. Ruhmkorff Coils.—It seems, as a result of experiments, that it is well to use a Ruhmkorff coil capable of giving a discharge spark as long as possible. Consequently, very powerful induction coils should be used. Those most used will give a discharge spark of 10 to 16 inches between points, but in operation these sparks are reduced so as to have a length of between 1 and 2 inches. These short sparks are thicker than the long ones.

All types of interrupters have been tried, those with turning contacts, mercury, hammer, etc., but no particular one shows any marked superiority. For long operation the best one of those mentioned is the hammer interrupter. It is certain that the frequency should be small. Marconi

has returned to the simple hammer interrupter after trying others. The Wehnelt electrolytic interrupter, which has failed with some, has given others excellent results.

349. Oscillators. — The majority of experimenters, including Marconi, use the spark gap of Hertz, with two small balls in air. The platinizing of these balls is unnecessary, but some experimenters advise that they be polished from time to time.

350. Antennæ.—Wires and other apparatus that may be connected to the balls on each side of the spark gap are called **antennæ.** This term does not include, however, the secondary of the induction coil. The spark gap and the two antennæ constitute the oscillator. An insulation of rubber along the vertical wire appears useful in diminishing its partial discharge by convection into surrounding moist air.

351. Critical Potential for Coherers.—In order to utilize the properties of the coherer, it is necessary that the critical potential at which the coherer breaks down shall not exceed the electromotive force of the cell plus the electromotive force of self-induction produced by the decrease or the breaking of the current in the local circuit containing the coherer and relay. It is then necessary that the inductance be as small as possible, and that the current flowing have but slight intensity. The first condition being difficult to meet, notwithstanding the use of non-inductive shunts around all inductive parts, it is necessary to reduce the current by the use of a low-voltage cell. The Lalande cell, which gives, with a negative electrode of tin, a potential of .25 volt, has given good results.

Very good results may be obtained with coherers using filings of gold, silver, or with silver alloyed with a hundredth part of copper, placed between German silver electrodes. The use of a slightly oxidizable metal allows one to raise the critical potential sufficiently to use a cell that will work the relay.

352. Self-Decohering Coherers.—The necessity of a tapper with existing coherers is very troublesome, and does not permit the use of a telephone as a receiver. Various experimenters have therefore sought coherers decohering spontaneously without tapping. Tommasina, using a coherer with magnetic filings, has attempted to replace the tapper by an electromagnet, magnetized only when the coherer is affected, thus attracting the filings and decohering them. It has been proved that in this arrangement, the filings become magnetized and then it is no longer possible to easily decohere them. He obtained a good automatic decohering coherer by using two German silver electrodes plunged in carbon powder similar to that used in telephone transmitters. It was apparently not successful for long distances.

SYNTONIC SYSTEMS.

353. A serious inconvenience charged against wireless telegraphy that interferes with its entry into the real domain of practice is the fact that, with the ordinary arrangement of apparatus, as already described, it is impossible to obtain, at the same station, two independent communications, every receiver placed in the radius of action of a transmitter being acted on by the waves sent out by the one transmitter. Various systems, founded upon different principles, have been proposed with a view to avoid this fault.

354. Sending Waves Out in One Direction Only. If it is desirable to direct the waves in a given direction, the vertical wire and earth connections are sometimes omitted and, as shown in Fig. 112, the spheres *g*, *h* of the oscillator are placed in the focal line of a metal cylindrical parabolic reflector *w v*. It is slightly advantageous for the focal length of the reflector to be equal to $\frac{1}{4}$ or $\frac{3}{4}$ of the length of the waves emitted by the oscillator. Moreover, the length and broadest diameter (across the opening of the reflector) should be at least double that of the wave length.

355. Messrs. Lodge and Muirhead have sought to obtain an electric resonance between transmitting and receiving circuits. For this purpose they make the *radiator* and the *collector*, as the oscillator and receiving circuits,

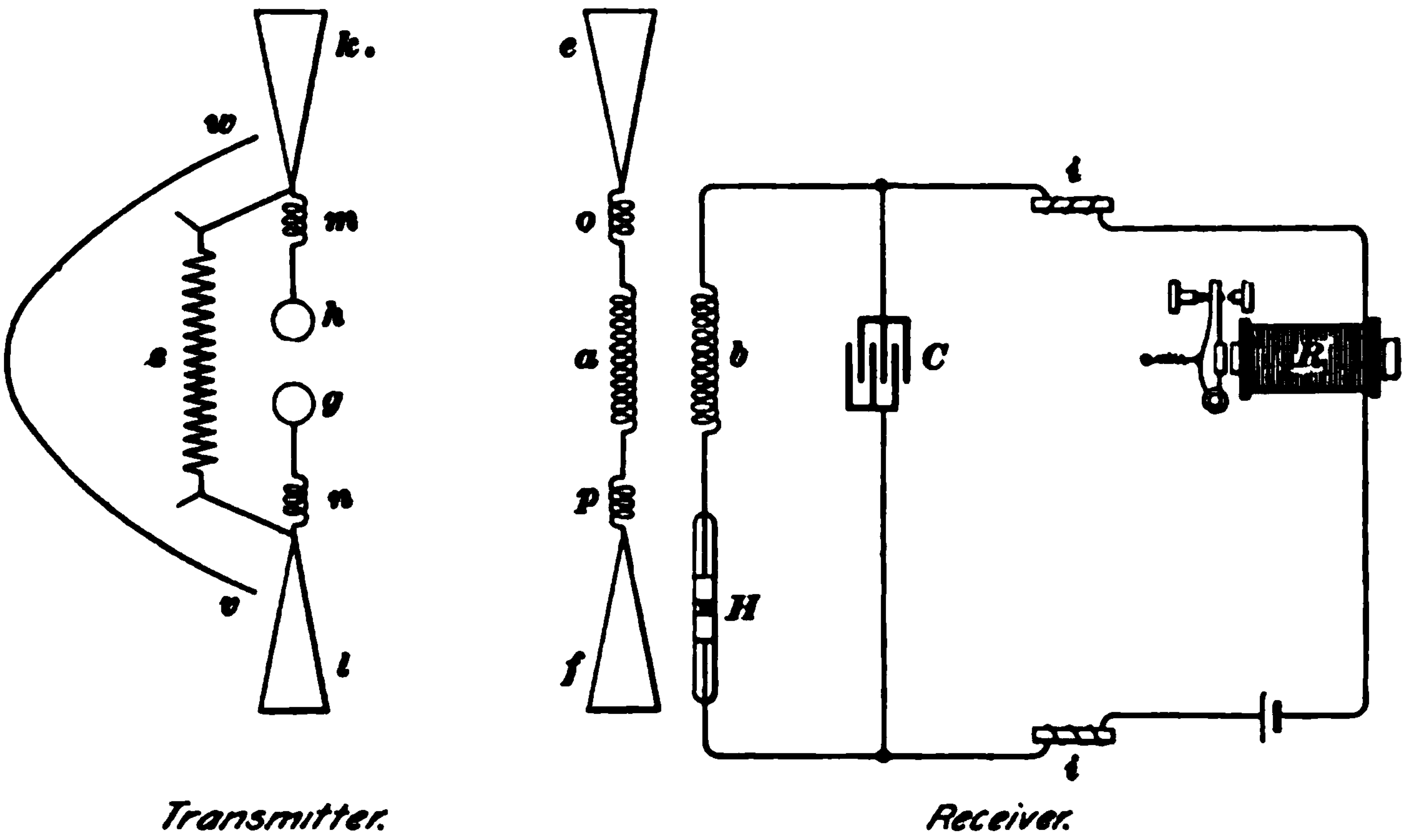


FIG. 112.

respectively, are frequently called, independent of all other apparatus, and tune these to the same period of oscillation by modifying the self-induction of a coil having a variable number of turns, and by adjusting the electrostatic capacity of the apparatus.

356. Tuning Transmitter and Receiver.—The transmitter and receiver may be tuned to emit and receive, respectively, waves of a certain length by attaching metal wings *e*, *f*, *k*, *l* to them, as shown in Fig. 112. Between the wings *k* and *l* and the balls *g* and *h* of the oscillator are connected two coils *m* and *n* having a small inductance. The inductance of these coils and the area, and, therefore, the capacity of the wings *k* and *l*, are adjusted to be in tune with the wave length emitted by the oscillator. Usually but little or no inductance is required at *m* and *n*. The length of the wings should approximate the length of the wave emitted. The entire transmitting apparatus is not

shown here, since it would be the same as that already given. The secondary of the Ruhmkorff coil is shown at *s*. This arrangement was devised by Professor Lodge.

At the receiving station, *a* is the primary and *b* the secondary of an induction coil similar to that already described in connection with Fig. 109. The wings *e* and *f* and the inductance coils *o* and *p* must be adjusted until this receiver is in tune with the transmitter. There would often be sufficient inductance in the coil *a*, so that the coils *p* and *o* would not be required. The capacity of the wings *e* and *f* are readily adjusted by making them of very thin sheet metal and rolling them up upon themselves until they have the proper length and capacity. This may be determined by holding the receiver near the oscillator and in the focal line of the reflector *v w* (if one is used), and making a minute air gap somewhere near the middle of the collector between the two wings *e* and *f*. The wings have the proper length when the distance from the oscillator to the receiver, at which a spark will pass across the minute air gap in the collector, is a maximum. This spark is caused by electric oscillations in the system *e o a p f* when the latter is in tune with *k m h g n l*. When placed at the distant station, the wings may have to be slightly readjusted.

Marconi relies on the proper adjustment of capacity and self-induction to obtain resonance. He connects a long metallic sheet to the antennæ on each side of the spark gap, that is, in the vertical wire, and in *e G* in Fig. 109. He sometimes includes on each side of the spark gap a coil possessing self-induction.

357. These methods have not given good results, probably from the fact that the oscillations produced in the vertical wire at the sending station are very rapidly damped and have not time to establish actual resonance at the receiving station. That is, the current wave produced in the receiving circuit by an arriving electromagnetic wave dies out before another electromagnetic wave arrives. Thus one current wave is not helped or pushed forwards by a

following wave, although the two may be in perfect tune or unison.

358. Results Attained in Selective Signaling.—While it is possible to make a receiver respond to only one transmitter, up to the present time it has not given very good results so far as the distance over which signals may be sent is concerned. A reflector, if used, must, of course, be turned in the proper direction, which is a disadvantage.

In the fall of 1900, Marconi succeeded in simultaneously sending two different messages between two stations in England 30 miles apart, and they were recorded upon Morse registers without delay or mistake. Each receiver in this case was connected to the same aerial wire about 40 feet high. Marconi's arrangement in these trials has not been published at the present time. Other trials showed that messages could be sent from one station to another while between two other stations messages were also being sent, the line between the first two intersecting the line between the second two stations. In March, 1901, Marconi stated that by his system, messages from five different places could be received simultaneously at one point.

THEORY OF WIRELESS TELEGRAPHY.

359. The phenomena of wireless telegraphy are very complex and have given rise to various interpretations. The first idea is to suppose a mutual induction between the two nearly parallel vertical wires. But this will not explain the propagation of waves, and appears certainly to fail, when in consequence of the rotundity of the earth or by an obstacle, the vertical wires are screened from one another. Certain authors have claimed an effect of electrostatic capacity between the uprights, but such an effect would diminish in inverse proportion as the cube of the distance, and very quickly reduce to nothing. Others, impressed by the influence of the ground wire at the sending station, have been led to see in this propagation an effect of conduction

by the earth. This will explain why transmission is better over sea than land. But this will not account for the excellent results obtained by means of a vertical wire hung from a balloon.

360. In reality, the phenomena appear to be a combination of several effects, one or the other of which predominates, according to the conditions. Electric oscillations are produced along the wire and in the space between the vertical wire and the earth. From the seat of this disturbance originate the waves, which are propagated in all the surrounding space. These waves form surfaces of revolution around the vertical wire. The lines of electric force are in meridional planes and are perpendicular to the earth; the magnetic lines of force are in horizontal circles having the vertical wire as a common axis. As a result of the effect of concentration, well known in the propagation of waves along wires or metallic surfaces, the electric density is much greater at the surface of the earth directly connected with the oscillator than in the atmosphere, and in large part the magnetic lines appear to slip along the earth. In the case of a hill intervening, it is supposed that the waves slide up and over it. This concentration, moreover, is the greater the more perfect the conductivity of the surface over which the waves proceed, and the loss of energy in this transmission is thereby lessened over a smooth surface. Yet this concentration does not prevent the diffusion of an important part of the energy into all space, under the form of hemispherical waves, the effects of which are less intense than those near the earth, but, nevertheless, noticeable.

One of Marconi's assistants stated that the amplitude of the vertical waves generally used proved to be about four times the length of the vertical wire. This would make the amplitude of vibration 600 feet for the waves that left the top of a vertical wire 150 feet high.

361. The receiving wire, cut at all points by the lines of magnetic force, is the seat of a resultant electromotive

force proportional to the intensity of the field and to the rapidity of the oscillations. The higher the vertical wire, the more lines of force are cut. With a given length, fewer lines are cut as we ascend farther from the earth. It is not necessary that the receiving vertical wire be connected to the earth, but the range appears to be slightly extended, due to the conduction over the surface of the earth as mentioned elsewhere.

It is theoretically important to increase the electrostatic capacity, the potential used, and the frequency of the oscillations, and to reduce the self-induction as much as possible.

362. If a circuit having certain resistance, inductance, and capacity be placed in a region in which waves are passing in such a position that the successive waves can induce currents in it, then each wave will tend to slightly increase the intensity of the current induced by the preceding wave, provided the waves have a certain particular frequency. The oscillations will increase in intensity, just as small pushes given to a pendulum at the proper times will make it swing violently. Such a system is said to be in tune with the waves or the generator that emits the waves. The generator and receiver are also said to be in resonance or syntony with each other.

If R is less than $\sqrt{\frac{4L}{Q}}$, in which R is the resistance, L the inductance, and Q the capacity of the system, then the discharge due to the electrostatic capacity of the system gradually expends itself in a series of oscillations, the periodic time T of which is given by the expression $T = \frac{2\pi}{\sqrt{\frac{1}{LQ} - \frac{R^2}{4L^2}}}$.

If R is very small in comparison to the other quantities, as is usually the case in apparatus designed to emit electric waves, then $T = 2\pi\sqrt{LQ}$. Now, as T may be varied by changing either one or both L and Q, a very wide range of vibration may be secured. Knowing T and the rate of propagation of the wave (approximately the velocity of light

in air, or 29,857,000,000 centimeters per second), the wave length, which we will designate by l, is the product of this periodic time and the velocity, or it is equal to the velocity divided by the frequency.

363. Wave Length.—In case of an oscillator having simply two spheres of equal size separated by an air gap, as shown in Fig. 108, the wave length l is given approximately by the formula

$$l = 7\,D, \qquad \textbf{(26.)}$$

in which D is the diameter of the spheres.

In the case of one large sphere separated by air gaps from two smaller spheres, one on each side, as shown in Fig. 109, and when the diameters of the small spheres and the length of both conductors or rods connected to these small spheres are very small in proportion to the diameter of the larger central sphere, the wave length is given approximately by the formula

$$l = 1.3\,D, \qquad \textbf{(27.)}$$

in which D is the diameter of the large central sphere. In other cases the formulas become too complicated to be given here.

364. Energy.—The energy represented by the waves that reach the receiving station varies as the square of twice the distance between the oscillator and coherer. Hence, the energy required to transmit signals increases enormously as the distances become greater. There is little or no secrecy except by code; the average speed is not over 12 words per minute; and an ordinary receiver is generally useless, except for short distances, when it is within range of two stations that are transmitting at the same time. These objections will probably be successfully overcome in the future

365. Effect of Weather and Surface of the Earth. The quality of communication is about the same under

all conditions of fog, rain, wind, etc. However, it is decidedly easier to establish communication over water than over land. The heights of vertical conductors required over land are always considerably greater than those sufficing for sea communication over the same distance.

366. Laws for Height of Vertical Wires.—Marconi has deduced from numerous experiments on sea the following laws, which have been also verified by Mr. Gravey, Engineer of the British Post Office:

First.—To obtain the maximum useful effect, the antennæ of the two stations should be equal and parallel.

Second.—The height H of the vertical wires required for good communication is related to the distance D between the vertical wires by the formula

$$H = a\sqrt{D}, \qquad (28.)$$

a being a coefficient depending on the nature of the apparatus used. This distance for clear space, as given by the formula, is diminished at least one-half when the two stations are separated by high intervening obstacles.

The advantage of having the vertical wires of like height seems to be very slight, and the results appear almost the same if the height of the vertical wires vary simultaneously, keeping their sum constant. For best results they should not differ in height more than 15 to 30 feet.

367. Influence of Curvature of Earth.—It seems as though the curvature of the earth can have but little influence, if any, on the height required for the vertical wire. During the English naval maneuvers in the summer of 1899, Marconi used a vertical wire 150 feet high at each station 75 miles apart at times. In this case there was a hill of water, due to the curvature of the earth, 35 miles long and 700 feet high at the center (550 feet above a straight line joining the top of the wires). Possibly the vertical wire is necessary because its use lengthens the waves and propagates at least some of them in a plane vertical to the surface of the

earth and they are therefore less likely to be absorbed by it. The fact that the waves are lengthened makes them more penetrative and capable of affecting a receiver at a greater distance.

368. Results.—As an instance of distances attained, in 1900 Marconi established communication between two stations 84 miles apart with wires 135 feet high. A straight line joining the upper extremities of the two vertical wires would pass 900 feet below the surface of the sea.

Experiments made inland are less brilliant. In many cases recourse has been made to captive balloons or kites to obtain antennæ sufficiently high. By such means Marconi, in 1899, telegraphed between Salisbury and Bath, 33.5 miles. It was stated in March, 1900, that successful communication had been held in South Africa over a distance of 70 miles by using kites to hold up the vertical wires. This method depends on a steady wind at both stations and often when there is a good wind at one station there is none at the other. It does not appear, in spite of the announcements of the results in the Transvaal, that much use has been made of wireless telegraphy in military operations. At present it seems that messages may be sent about three times as far on the ocean as on land.

In the fall of 1900, Marconi succeeded in transmitting messages from Poole to the Isle of Wight, a distance of 30 miles, by the use of metal (zinc) cylinders 4 feet in height, hung about 25 feet from the ground, thus dispensing with the 177-foot uprights previously used over this range. At the same time he transmitted two simultaneous messages without interference. No explanations concerning the method used have been made public.

In February, 1901, Marconi established perfect communication with vertical wires 100 feet high between St. Catherines, on the Isle of Wight, and Lizard Head, a distance of 200 miles, practically over water the entire distance. This is the longest transmission recorded so far and constitutes a considerable step in advance.

UTILIZING ELECTRIC RAILWAY CURRENT FOR TELEGRAPH CIRCUITS.

369. The following method of supplying local and main-line telegraph circuits with current from the 500-volt circuit of electric railways was described in the "Telegraph Age" by Mr. Wm. H. Deane, who has employed it on the

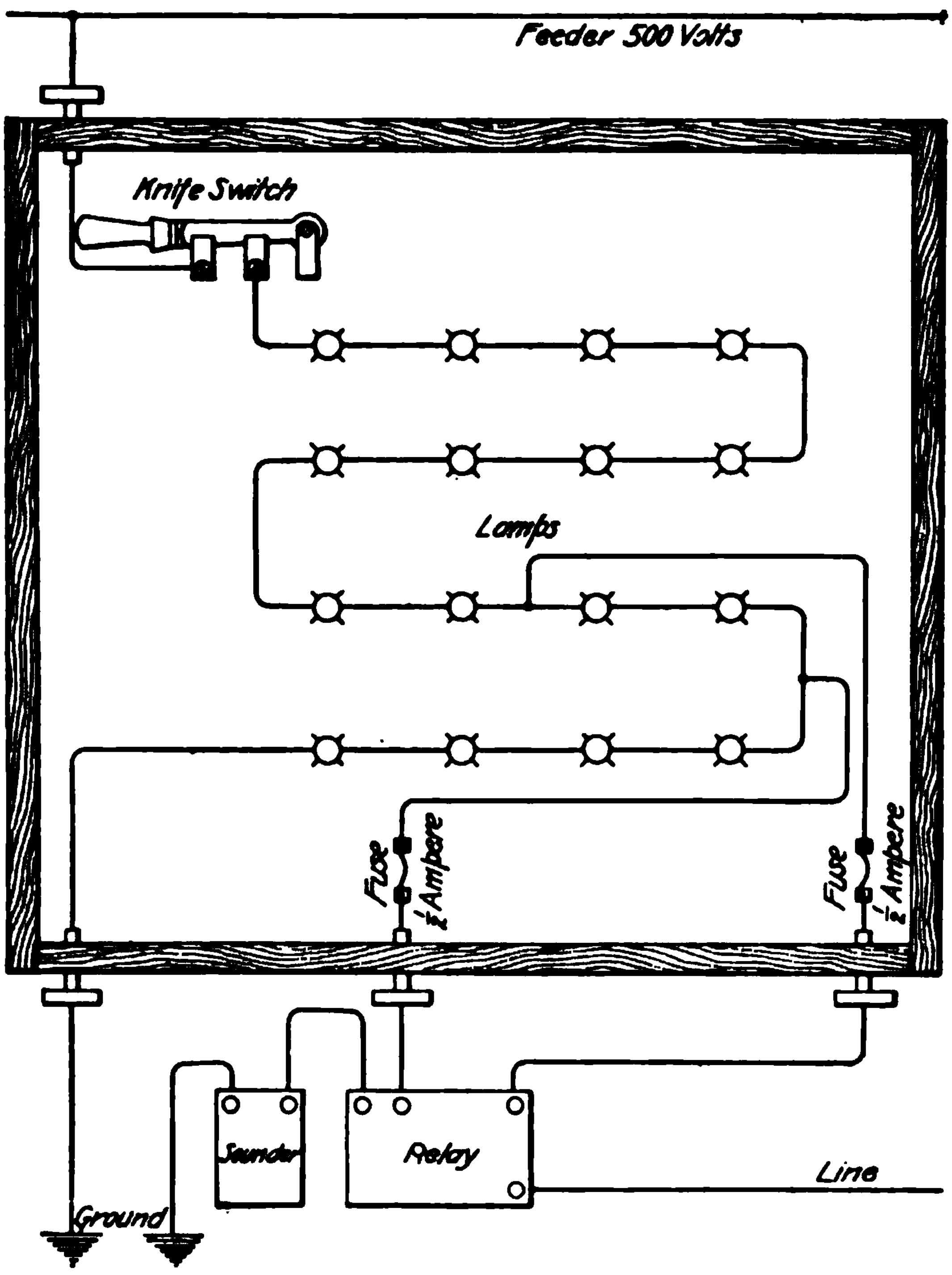


FIG. 113.

telegraph circuits of the Brooklyn Rapid Transit Company since July 1899. The method is illustrated in Fig. 113.

"A wooden box 18 inches square and 8 inches deep is lined with thin sheet asbestos and fitted with sixteen 110-volt lamps of 16 candlepower each and wired in series. The current is led from the feeder through the regulation

porcelain tubes used in electric light work to a small knife switch located in the box and then through the bank of lamps, and out through another tube and grounded, preferably to the rail.

"One end of the telegraph line or local circuit that is to receive this current is grounded and the other end is brought into the box of lamps and passed through a half-ampere fuse before reaching the lamp connection. In supplying a main line, it is of course understood that this apparatus can only be applied at one end of a grounded telegraph wire. To ascertain quickly the point that will furnish the needed current, the end of this conductor should be touched to the lamp connections and, starting from the grounded end of the bank, moved lamp by lamp upwards until the instrument in the circuit shows that it is supplied with the proper amount of current to do the work required. When this is decided upon, the wire can be permanently fastened to the particular connector selected. The following telegraph lines and quite a number of locals have been equipped in this way and are giving perfect satisfaction: Brooklyn Elevated Division No. 1 telegraph line consists of 25 miles of No. 12 insulated iron wire and looped into 24 relays of 50 ohms resistance each. This circuit works strongly and is tapped between the sixth and seventh lamps from the ground end. Kings County Elevated Railroad Division, consisting of two line wires each 8 miles long, of the same wire as mentioned above, and equipped with 17 relays of 30 ohms resistance, is tapped between the fifth and sixth lamps. Local 4-ohm sounders work strongly when tapped between the fourth and fifth lamps, and when sounders of 20 or 30 ohms are used, excellent results are obtained by tapping between the first and second or second and third lamps."

370. Precautions to be Carefully Observed.—"Care should be taken not to unscrew any of the lamps between the tap point and the ground without first opening the knife switch, as the telegraph circuit is instantly flooded

with a rather heavy current, and although the fuse would protect the circuit, still an unpleasant shock might be given to some one working the wire at the time. The same trouble would be experienced should a filament break in one of the lamps on this end of the bank of lamps; but this rarely happens, as these lamps are not subjected to the hard usage of those used for lighting purposes. Only one case of this kind occurred in a year on the above circuits. This was caused by an old lamp being accidentally used in setting up the apparatus. Great care should be taken that the entire work is done on the strict lines laid down by the underwriters and boards of electrical control."

371. There has not been much trouble from variations of current, and then only at points where there are no feeders and where a tap was made to the trolley wire direct. Over 200 gravity cells have been displaced, and these boxes, enabling the electric railway current to be used, are being installed wherever locals are used, with the most gratifying results.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the various Examination Questions that follow are grouped into sections having the same titles as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper has been carefully studied.

TELEGRAPHY.

(PART 4)

EXAMINATION QUESTIONS.

(1) What is a telegraph repeater?

(2) (*a*) What must be the position of the switch arm *k* in Fig. 2, in order that the eastern circuit may repeat into the western circuit? (*b*) Explain the operation of repeating from the eastern line into the western line with the button repeater shown in Fig. 2.

(3) What is a button telegraph repeater?

(4) State four ways in which the two line circuits may be used, and also the corresponding positions of the switches *M* and *g* in Fig. 1.

(5) Why should the sending be heavy or firm on circuits containing repeaters?

(6) Name a telegraph circuit mentioned in connection with the subject of "Telegraph Repeaters," or, preferably, one coming under your own observation, that requires one or more repeaters, and state its length.

(7) Why are repeaters needed?

(8) For what purpose are button repeaters used?

(9) (*a*) What is an automatic repeater? (*b*) Why is an operator needed for these repeaters?

(10) (*a*) What is an artificial line? (*b*) Why is it used?

(11) What is the chief function of an automatic repeater?

(12) (*a*) What is duplex telegraphy? (*b*) What is diplex telegraphy?

(13) (*a*) Are all circuits normally closed or open in a Milliken repeater? (*b*) When the key at the western station is opened, why do the eastern relay and the transmitter on the same side remain inactive, that is, closed?

(14) (*a*) On what principle does the bridge duplex system of telegraphy depend? (*b*) What parts in the system are arranged the same as for the differential duplex? (*c*) What instrument in the ordinary Wheatstone bridge has the same position as the relay in this system?

(15) How much movement should the lever of the Milliken transmitter have?

(16) Why was a third coil, condenser, and two resistances, known as the *Smith device*, used in the Western Union quadruplex system?

(17) If the stronger current in a quadruplex system is too small, notwithstanding that the dynamos or batteries are up to full pressure, where would the trouble probably be found?

(18) Describe the use of the induction coil in the Jones quadruplex system.

(19) (*a*) What is a side-line repeater? (*b*) Name two repeaters that may be used as side-line repeaters.

(20) Under what circumstances do no currents actually flow in the line in the Jones quadruplex system?

(21) On what principle does the successful operation of the Toye repeater depend?

(22) (*a*) In the normal condition of the Neilson repeater what instruments are closed and what ones are open? (*b*) What instruments in the Neilson repeater are open and what instruments are closed when the key at the distant western station is open?

(23) State some advantages and disadvantages of the Toye repeater.

(24) Fill in the blank spaces for the ninth combination in Table 3, following the same method of notation as is used in the part of the table that is complete.

(25) (*a*) What is the distinctive feature of the Weiny-Phillips repeater? (*b*) What is the normal condition of all the circuits?

(26) (*a*) What is meant by the single-current system? (*b*) What is meant by the double-current system?

(27) In the Weiny-Phillips repeater shown in Figs. 13 and 15, what instruments are open and what instruments are closed when the key at the distant eastern station is open?

(28) What is the distinguishing feature of the Horton repeater?

(29) What kind of relays are necessary in a double-current system?

(30) (*a*) In the Atkinson repeater, what instruments are closed in the normal condition? (*b*) What circuits are closed and what circuits are open in the normal condition? (*c*) What instruments and circuits are open and what instruments and circuits are closed when the eastern key is open?

(31) Where is the double-current system used?

(32) What is a polarized relay?

(33) In the Horton repeater, through what magnets only is current flowing, and where are circuits open and where are circuits closed at the repeater when the eastern key is open?

(34) In multiplex systems, what is meant by a *static balance?*

(35) How are the sounders arranged at the battery station in the Morris single-battery duplex system?

(36) (*a*) State two ways in which condensers may be connected in an artificial line. (*b*) How are condensers adjusted in each case so as to charge and discharge in the same manner as the line?

(37) (*a*) What is the object to be kept in view in winding differential relays? (*b*) In what three ways is it possible to wind a relay differentially?

(38) How is the Stearns differential duplex balanced?

(39) (*a*) Why is the polar duplex superior to the Stearns duplex? (*b*) What is the essential feature of the polar duplex?

(40) (*a*) Why is a continuity-preserving pole changer preferable to one that opens a circuit in the act of reversing the direction of the current? (*b*) Why is the continuity-preserving pole changer not used in connection with dynamos?

(41) When dynamos are used in the polar duplex and quadruplex systems, why are at least two machines used, instead of reversing one machine as would be the case if a battery were used?

(42) (*a*) What is the so-called ground coil in the polar duplex and quadruplex systems? (*b*) To what is its resistance equal? (*c*) Why is it used?

(43) In duplex and quadruplex systems, (*a*) what is meant by the receiving circuit, and (*b*) what is meant by the sending circuit?

(44) What are the four important steps taken in balancing the polar duplex?

(45) (*a*) What is meant by centering the armature of the polar relay? (*b*) How is it done?

(46) In multiplex systems, what is meant by a *resistance balance?*

(47) In balancing a quadruplex system, what instrument should you go by?

(48) (*a*) In what respect is the bridge duplex inferior to the differential duplex? (*b*) In what respect is it superior to the differential duplex?

(49) What is the distinctive and advantageous feature of the Morris single-battery duplex?

(50) What is a continuity-preserving pole changer?

(51) If the margin is too small in a quadruplex system, where would the trouble most likely be found?

(52) How may two messages be sent in the same direction over the same wire at the same time?

(53) (*a*) What is meant by the short-end and long-end batteries? (*b*) What is meant by the No. 1 and No. 2 sides of a quadruplex system?

(54) What is the advantage and disadvantage of a resistance in the circuit between the transmitting apparatus and the relays in the quadruplex system?

(55) (*a*) What is meant by the term margin used in quadruplex telegraphy? (*b*) What are the retarding coils and why are they so called?

(56) Explain briefly how currents of two different strengths are obtained in the line in the Western Union dynamo quadruplex system.

(57) In the Jones quadruplex system, how is the current reversed in direction and how is it changed in strength?

(58) How are the increase and decrease and reversal of the current obtained in the Healy quadruplex system?

(59) What is multiplex telegraphy?

(60) (*a*) Why are signals that pass through repeaters apt to be shortened? (*b*) How may the signals be made more intelligible?

(61) (*a*) What is the quadruplex system of telegraphy? (*b*) On what changes in the line current does it depend for its action? (*c*) How in the ordinary quadruplex system does each key govern its own sounder without affecting the others?

(62) What would indicate an open wire on a quadruplex system?

(63) What would indicate a defect in the ground-coil circuit in a quadruplex system?

(64) On what principles does the Morris single-battery duplex depend for its operation?

(65) In a quadruplex system, what would indicate a foreign current coming in over the line from a cross with another wire?

(66) How is the Frier self-polarizing relay adjusted ?

(67) What is the distinctive feature of the Houghtaling transmitter and pole changer ?

(68) Name in order the five steps given in the Jones method for balancing the quadruplex.

(69) How may a differential galvanometer be used to tell if the current divides equally between the line and artificial-line circuits ?

(70) Calculate the strength of current flowing in the line in the open and closed positions of the transmitter and the ratio of these two currents in the Healy quadruplex shown in Fig 75, when the line and artificial line each have a resistance of 1,800 ohms and the resistances *A*, *B*, and *C* possess 400, 800, and 267 ohms, respectively, and the dynamo generates an electromotive force of 220 volts.

(71) How are the sounders arranged on the neutral side of the Healy quadruplex ?

(72) What would indicate, in the Western Union dynamo quadruplex, a defect in the leak-coil circuit ?

(73) To what are most quadruplex troubles due ?

(74) In the Western Union dynamo quadruplex, calculate the currents and the ratio of the currents that flow in the line in the open and closed position of the transmitter when the resistance of the line is 1,800 ohms, the resistance of the leak coil 800 ohms, the added resistance 1,800 ohms, the resistance of the lamp in series with each dynamo 600 ohms, and the electromotive force of the dynamos 220 volts.

(75) What would indicate a defective ground wire, that is, a defective connection between the battery or dynamo and the ground in a quadruplex system ?

(76) After a careful balance of the quadruplex has been obtained and the incoming signals are still more or less interfered with directly the distant office begins to send on the polar side, where would you suspect the trouble to be ?

(77) (*a*) Where would you insert the wedge attached to an ammeter in order to readily measure the strength of the incoming current in the Western Union quadruplex? (*b*) where in the Postal Telegraph quadruplex?

(78) What would indicate a crossed or grounded line wire on a quadruplex system?

(79) (*a*) How would you adjust a dynamo pole changer? (*b*) What precautions must be taken in adjusting it?

(80) (*a*) In a quadruplex system, how would a defective cell in the long end of the distant battery be indicated? (*b*) How would a defective cell in the short end of the distant battery be indicated?

(81) (*a*) What trouble would be caused by a trolley current flowing through the line? (*b*) How would you determine whether the trouble is due to the trolley current? (*c*) How would it be remedied?

(82) In a quadruplex system, how would a defective tap wire at the distant station be indicated?

(83) What trouble would be encountered in attempting to balance a quadruplex if a condenser in the artificial line was punctured by lightning or otherwise?

TELEGRAPHY.

(PART 5)

EXAMINATION QUESTIONS.

(1) How may two polar duplex sets be arranged to repeat into each other?

(2) What is the difference in principle between the arrangements of duplex or quadruplex repeaters when dynamos are used and when gravity cells are used?

(3) In what two ways may quadruplex sets be arranged to repeat into one another?

(4) What are the distinctive features in the arrangement, when dynamos are used, of the local circuits on the Canadian Pacific Railroad telegraph system?

(5) State one advantage and one disadvantage of the Edison phonoplex system compared with the ordinary Morse system.

(6) What is a multiplex single-wire, or defective-loop, repeater?

(7) Why is the siphon in the Cuttriss submarine-cable recorder made to vibrate?

(8) What arrangement may be used to enable a branch office to call up the central office?

(9) (*a*) In the Van Rysselberghe simultaneous telegraph and telephone system, how many line wires are used and into what circuits including the earth are they arranged? (*b*) How many telephone and telegraph messages may be simultaneously sent by this method by using only one line wire? In this case how is the earth used?

(10) How is the siphon in the Cuttriss submarine-cable recorder made to vibrate?

(11) What is an artificial cable?

(12) (*a*) Explain briefly the principle of Cailho's simultaneous telegraph and telephone system. (*b*) How many messages, including both telegraph and telephone, may be sent simultaneously over the same circuit by this method, and what constitutes the complete circuit for each message?

(13) What kind of a repeater is the Downer?

(14) What method is used in duplexing submarine cables?

(15) (*a*) What kind of a repeater is the Moffat? (*b*) On what well-known repeater principle does it depend?

(16) What is the principle on which the Edison phonoplex is based?

(17) (*a*) Are the Moffat and Downer defective-loop repeaters suitable for repeating from one main line into a long branch line? (*b*) Give a reason for your answer.

(18) State the steps necessary in telegraphing a message by the Wheatstone automatic system.

(19) (*a*) What is the advantage of using automatic cable transmitters in place of transmitting by hand? (*b*) Name two automatic submarine-cable transmitters.

(20) On what principle does the Downer repeater depend?

(21) For what purpose is the Half-Milliken repeater used?

(22) In the normal condition, what circuits in the Half-Milliken repeater are closed and what ones are open?

(23) How are earth currents eliminated in submarine telegraphy?

(24) What may be accomplished by the Dillon branch-office quadruplex repeater?

(25) How is the same result that is accomplished by the Dillon branch-office quadruplex repeater in Western Union

offices obtained in Postal Telegraph offices, on account of the different arrangement of branch-office loops in the latter offices?

(26) What is a double-loop repeater?

(27) Explain the operation of the apparatus shown in Fig. 14, when the distant *B* and *C* stations desire to work double.

(28) In multiplex single-wire repeaters, where is trouble apt to occur, assuming that the duplex or quadruplex apparatus itself is in proper condition?

(29) What is the object of connecting together three multiplex sets as shown in Fig. 14?

TELEGRAPHY.

(PART 6.)

EXAMINATION QUESTIONS.

(1) Describe a test for locating a ground on a telegraph line when no good wire is available.

(2) What is meant by the sine-wave system?

(3) Explain briefly the steps necessary to send and to receive a telegraph message by the Delany chemical method.

(4) (*a*) What two types of galvanometers are used for making accurate tests on lines and cables? (*b*) Name the advantages and disadvantages of each.

(5) What are two serious objections or defects of wireless telegraph systems?

(6) What are the advantages and disadvantages of automatic systems, such as the Wheatstone, Delany chemical, etc.?

(7) What is a coherer?

(8) State the steps necessary in telegraphing a message by the Pollak-Virag system.

(9) What are the objections to the Pollak-Virag system?

(10) Describe briefly a method for determining the resistance of a line or of a ground circuit where there are at least two good line wires and a ground circuit between the same two stations.

(11) Explain the principle of the method of measuring insulation resistance with a galvanometer.

(12) Describe the Varley loop test for locating crosses on telegraph lines.

(13) (*a*) How may wires be identified at one end of a cable? (*b*) How may wires be identified at intermediate points in a cable without cutting them?

(14) In taking the galvanometer constant in the direct deflection method of measuring an insulation resistance, a deflection of 342 scale divisions was obtained, using a $\frac{1}{10}$ megohm box and a shunt having a multiplying power of 1,000; what was the constant?

(15) What is the most satisfactory instrument for the measurement of all ordinary resistances?

(16) After the constant of a galvanometer has been determined, and after the deflection produced by passing the battery current through the galvanometer and the insulation resistance to be measured has been noted, describe the calculation of the insulation resistance.

(17) Why may not the magneto-testing set be implicitly relied on in testing out long circuits either for continuity or grounds?

(18) A test was made to locate a ground on a line wire by the Murray loop method. At the distant station the bad wire was joined to a good wire connecting the same two stations, and the resistance of the loop so formed was measured by the Wheatstone bridge in the usual manner and found to be 515.58 ohms. The bridge was then connected with the two line wires as shown in Fig. 95. When balanced it was found that there were 1,000 ohms in the arm m, 1,000 in n, and 2,015 in p. The bad line was a No. 14 B. & S. gauge hard-drawn copper wire, having a resistance of 2.578 ohms per 1,000 feet at the temperature of the test. What was the distance in miles from the testing station to the fault?

(19) A test was made to determine the resistance of each of three line wires between the same two offices. The distant ends of two wires, which we will call x and y, were

joined together and the resistance of the loop so formed was found by means of a Wheatstone bridge to measure 1,077 ohms. Then the wire x was joined to the wire z at the distant end, and the resistance of this loop was found to be 1,130 ohms. Finally the distant ends of the wires y and z were connected and the resistance of this loop was found to measure 1,184 ohms. What is the resistance of each line between the two stations?

(20) If the total insulation resistance of a line wire of known length has been measured, how is the insulation resistance per mile calculated?

A KEY

TO ALL THE

EXAMINATION QUESTIONS

INCLUDED IN THIS VOLUME.

In the following pages are contained the Keys to the various Examination Questions immediately preceding. These Keys have been so arranged as to be similar in all respects to the Examination Questions to which they refer and are correspondingly numbered.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the Course.

TELEGRAPHY.

(PART 4.)

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(1) A telegraph repeater may be defined as an arrangement of apparatus for repeating signals from one main line into another main line. It is virtually a relay that is controlled by the sending operator at the end of one main line, and which, in turn, controls the second main line and hence the relay at the far end of it; the repeater itself is located at about the middle point of the distance covered. See Art. **1.**

(2) (*a*) The arm of the switch must be turned to the left, so as to connect *c* and *d*.

(*b*) Suppose that all circuits are closed and that the switch *k* is turned to the left, and that the eastern operator, in order to start sending, opens his key. This allows relay *R* to open, thus allowing sounder *S* to open. This opens the west line at *f*, and thus, since it is also open at *b*, the relay R_1, and also the relay at the distant western station, will open. The east line cannot open at the repeater because it is closed between *c* and *d* by the switch arm *k*. When the eastern station closes his key, the relay *R* and sounder *S* will close, thus closing the west line at *f*.

(3) A button repeater is one requiring that a button or switch should be turned by the hand of an operator at the

repeater in order to change from repeating in one direction to repeating in the other direction.

(4) With the switch *g* closed and *k* connecting *a* with *d*, the west line may repeat into the east line; with *g* closed and *k* connecting *b* with *c*, the east line may repeat into the west line; with *g* closed and *k* connecting *c* and *d*, the east line and the west line may be used independently; with *g* open and *k* connecting *c* and *d*, the west line and the east line are connected straight across.

(5) The sending should be heavy or firm; that is, the signals should be somewhat prolonged, because the current requires time to rise from zero to its maximum and to fall again to zero on account of the electrostatic capacity of the line and the inductance of the relays, and because time is also required for the various armatures to move across the gap between the two stops.

(6) Line from San Francisco to New Orleans, a distance of 2,484 miles, with one repeating station. See also Art. **4.**

(7) There are three reasons: *First*, as a line increases in length, the working efficiency decreases until it becomes so small that satisfactory signals cannot be transmitted no matter how much the battery power is increased. *Second*, as a line increases in length, the resistance increases, and, consequently, the electromotive force must be correspondingly increased, assuming that the insulation remains perfect; if it does not, the electromotive force must increase faster than the resistance. But it is impractical to use over 400 volts as an extreme limit, and 300 is usually considered very high for single working. *Third*, as a line increases in length, the electrostatic capacity increases until the latter seriously diminishes the speed of signaling. These three causes combine to limit the length of line over which it is practical to signal without using repeaters. See Art. **2.**

(8) Button repeaters are generally used only for temporary purposes.

(9) (*a*) An automatic repeater is one that will *automatically repeat in either direction*, that is, it does not require an operator at the repeater to turn a switch when the direction of sending is to be reversed.

(*b*) To adjust the instruments and care for the batteries. Besides doing other work, one operator may look after a number of repeater sets.

(10) (*a*) An artificial line is a branch circuit to the ground having the same resistance and capacity as the line. The resistance and capacity must be properly arranged so that the artificial line will not only have the same resistance and capacity but will also charge and discharge at the same rate as the line.

(*b*) It is used in order to make the current from the home battery divide equally through the line and artificial line, so that it will not energize the differentially wound relay or relays at the home station.

(11) The chief function of an automatic repeater is to keep the sending circuit at the repeating station closed as long as this circuit is repeating into the other or receiving circuit. See Art. **15.**

(12) (*a*) See Art. **71.**

(*b*) See Art. **72.**

(13) (*a*) Closed.

(*b*) When the key at the western station is opened, the western relay of the repeater Fig. 3 opens the local circuit through the magnet S_1 of the transmitter T_1, because M_1 does not release its armature. The transmitter T_1 breaks two contacts, one slightly before the other. The contact x_1 that is broken first opens a local circuit through the extra magnet M on the opposite, or eastern, side, causing this extra magnet to release its armature and hold the contact at y closed. Thus the transmitter T on the same, or eastern, side and the western line is held closed. The second

contact a_1 that is broken at the western transmitter T_1 opens the eastern main line, but the armature g of the eastern relay R is not released, although the eastern relay R is demagnetized, and, hence, the local circuit controlled by the armature g is not opened, because the armature is held against the contact or front stop y by the stronger spring s that acts on the armature o of the extra magnet. Hence, the armature of the eastern relay R always remains against its front stop y and, therefore, keeps the transmitter T on the same, or eastern, side, and, consequently, the western line, closed at a while the western key is being operated. Moreover, the circuit through the extra magnet M_1 is kept closed at x by the eastern transmitter, thus allowing the western relay R_1 to have full control of its armature g_1.

(14) (*a*) On the principle of the Wheatstone bridge.

(*b*) The battery, key, and artificial line.

(*c*) The galvanometer.

(15) Only enough movement to break the circuit, or about $\frac{1}{32}$ inch. See Art. **21.**

(16) It was used to obviate or reduce the mutilation of signals made on the neutral relay when it should remain closed This breaking up of a signal is due to the interval of no magnetism in the neutral relay when the distant pole changer reverses the distant full (or long end) main battery. See Art. **165.**

(17) In a double contact between the tongue of the transmitter and both the upper and lower contact points, due to an improper adjustment of the transmitter. See Art. **267.** If the system was previously used as a duplex, the small margin may be due to an extra resistance that was then inserted in the battery circuit, but it should have been cut out before attempting to again work the system as a quadruplex. See Art. **268.**

(18) See Art. **204.**

(19) (*a*) A side-line repeater is one arranged to repeat from a main line that runs through a repeating station into a side line that branches off from the repeating station.

(*b*) Most any single-line automatic repeater given, except, perhaps, the Toye, may be used as a side-line repeater.

(20) This condition exists for four different combinations of the four keys, which are as follows: All four keys open; all four keys closed; the pole-changer keys Pk and Pk_1 closed and the transmitter keys Tk and Tk_1 open at both terminal stations; the pole-changer keys Pk and Pk_1 open and the transmitter keys Tk and Tk_1 closed at both stations. See Fig. 69 and combinations 1, 6, 11, and 16 in Table 3.

(21) The Toye repeater depends for its operation on the substitution of a resistance equal to that of the receiving line in the place of the latter at the instant that the receiving circuit is opened, the resistance being substituted in place of the receiving line in such a manner as to hold closed the relay and transmitter that control the sending circuit, and, consequently, holding the sending circuit itself closed at the repeater. See Art. **23.**

(22) (*a*) In the normal condition of the Neilson repeater, which is shown in Fig. 10, the relays R and R_1 and the transmitters T and T_1 are closed and the repeating sounders RS and RS_1 are open.

(*b*) The relays R_1 and R, the transmitter T_1, and the repeating sounder RS are open. The repeating sounder RS_1 and the transmitter T are closed.

(23) The Toye repeater is extremely simple, and requires comparatively few pieces of only standard apparatus. On the other hand, it is hard on the batteries, hard to keep adjusted in changeable weather, and is not readily available as a side-line repeater. See Art. **25.**

(24)

TABLE 3.

NINTH COMBINATION.

No.	Keys				Pressure at Point		Current in			Effective Current.		Relays Operated.			
	West		East		h West	h_1 East	West	Line	East	West.	East	West		East	
	PK	TK	PK_1	TK_1			AL	L	AL_1	Relays NR and PR	Relays NR_1 and PR_1	PR	NR	PR_1	NR_1
9	Open	Open	Open	Closed	-100	-300	$\frac{100}{R}(x)$	$\frac{200}{R}(y\,x_1)$	$\frac{300}{R}(x_1)$	$\frac{300}{R}(y\,L)$	$\frac{100}{R}(x_1\,A\,L_1)$	Open	Closed	Open	Open
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

The following explanation will show how to determine the direction of the effective currents in the line and artificial-line coils of the relays used in the quadruplex system. It is necessary to bear in mind that *PC* operated by the key *Pk* is the pole changer, and serves to control only the *polarity* of the current that is directed toward the line. *T*, operated by the key *Tk*, is the transmitter, and controls only the *strength* of the current, *irrespective of its polarity*. Thus, when the lever of the pole changer *PC* is unattracted, the polarity of the current directed toward the line will be negative no matter what position the lever of the transmitter *T* occupies. When the lever of the pole changer *PC* is attracted, the polarity of the current sent to the line will be positive no matter what position the lever of the transmitter *T* occupies. In a similar manner, the voltage impressed upon the line will be the smaller of the two if the lever of the transmitter is unattracted, and the larger if it is attracted, regardless of the position of the lever of the pole changer *PC*. In working out the table, reference should be made to Fig. 54 or Fig. 55, and it should be remembered that the potential at the points h and h_1 may always be considered as determined by the positions of the keys at the corresponding end of the line. Take, for instance, the 9th set of combinations, the one left unsolved in Table 3. Both of the western keys are up, that is, open. The fact that the key controlling the pole changer *PC* is open determines the fact that the polarity is negative, and the fact that the key controlling the transmitter *T* is open determines the fact that its voltage is 100 and not 300. We therefore have −100 as the potential at h. In a similar manner, the fact that the key controlling the pole changer PC_1 at the eastern end of the line is up determines the fact that the polarity is negative, while the fact that the key controlling the transmitter T_1 is closed determines the fact that the voltage is 300 and not 100; thus, we have a potential of −300 at the point h_1 at the eastern end of the line. The determination of the direction in which the current flows in either branch is now a simple matter. Inasmuch as

the potential at the point h at the western end of the line is -100, we know that current will proceed from the battery B_1, Fig. 54, to earth at G, then to the earth at G_1, and up through the artificial line to the point h and through f, m, d, b, v, z, and q, back to the battery B_1. This direction of the current through the artificial-line circuit corresponds to the arrow x. The strength of the current in amperes will be, according to Ohm's law, 100 volts divided by R ohms, that is, $\frac{100}{R}$, R being the resistance of the artificial-line circuit. We therefore obtain for the current in the western artificial line $A\,L$ the value $\frac{100}{R}\,(x)$ for insertion in column 8. To determine the line current, we have only to calculate the difference of potential between the points h and h_1 at the eastern and the western end of the line. Evidently, the difference of potential is 200 volts, and, therefore, current will flow from west to east in the line, its direction corresponding to the arrows y and x_1 and its strength by Ohm's law is 200 divided by R. This current does not flow through the artificial line at either end, but through the batteries, pole changers, and transmitters at each end and through the line itself. We have, therefore, in column 9 for the line current, $\frac{200}{R}\,(y\,x_1)$. The potential at the point h_1 at the eastern end of the line is -300. Therefore, current will flow from the whole battery B_2 and B_3 in series to ground G_2, and up through the artificial line $A\,L$, and back in the direction of the arrow x_1 to the battery. The strength of this current will be $\frac{300}{R}$. We therefore have for the current in the eastern artificial-line circuit $\frac{300}{R}\,(x_1)$ for insertion in column 10. Examining now the conditions with a view to determining the effective current in the set of relays, we find that at the western end there is a current of $\frac{200}{R}$ in the direction of the arrow y in the line, while there is

a current $\frac{100}{R}$ in the artificial line $A\,L$ in the direction of the arrow x. These two currents are of such direction as to add their effects; hence the effective current is equivalent to $\frac{300}{R}$ (y) in the line coils and zero current in the artificial-line coils of the relays. We therefore have for the effective current in the western relays $\frac{300}{R}$ ($y\,L$) for insertion in column 11. At the western station this current, being strong enough, closes the neutral relay $N\,R$, but it is not in the proper direction to close the polar relay $P\,R$. At the eastern end of the line we have a current of $\frac{300}{R}$ in the artificial line in the direction of the arrow x_1 and of $\frac{200}{R}$ in the line in the direction of the arrow x_1. These currents, both flowing toward the point h_1, act differentially on the relay coils, and, hence, their difference must be taken. There is, therefore, a predominating current of $\frac{100}{R}$ in the artificial line $A\,L_1$ in the direction of the arrow x_1. The effective current in the relays at the eastern end of the line and to be inserted in column 12 is, therefore, $\frac{100}{R}$ (x_1 $A\,L_1$). This current is not strong enough to close the neutral relay $N\,R_1$ nor in the proper direction (see Art. **153**) to close the polar relay $P\,R_1$ at the eastern station.

(25) (a) The distinctive feature of the Weiny-Phillips repeater is the construction and winding of the extra magnets. They are differentially wound, and consist of one core with its winding enclosed in a soft-iron cylinder in such a manner as to form almost a closed path for the lines of force and, hence, make a very efficient electromagnet. The core is not magnetized when equal currents flow in both windings.

(b) Closed.

(26) (*a*) A single-current system is one like the Morse, in which the current flowing in either direction will make dots and dashes, spaces being made by breaking or stopping the current.

(*b*) A double-current system is one in which a current in one direction produces dots and dashes, a current in the opposite direction being required to terminate a dot or dash and start a space.

(27) When the eastern key in the Weiny-Phillips repeater is open, there is no current flowing through the relay magnet R, but there is current flowing through both coils of M; hence, the circuit is open at y. Consequently, the transmitter T is open. This opens at x one coil of M and at a the western line that passes through R_1. Consequently, M_1 is energized and although R_1 is deenergized, nevertheless the circuit through the magnet of the western transmitter T_1 is held closed by the armature at the front stop of the relay R_1. Therefore, T, M, and R are not energized in such a manner as to hold their armatures closed, but the western transmitter T_1 and the extra magnet M_1 are energized and hold their armatures closed in spite of the fact that there is no current through R_1.

(28) The distinguishing feature of the Horton repeater is the holding of the circuit of the transmitter on the sending side closed by the force of gravity, which alone acts on the relay armature when neither the relay nor the extra magnet are energized.

(29) Polarized relays are necessary in double-current systems.

(30) (*a*) In the normal condition, all instruments in the Atkinson repeater are closed.

(*b*) All circuits, except the two ending at f and f_1, are closed.

(*c*) The circuits through the magnets of the relay R, the transmitter T, repeating sounder RS_1, and the relay R_1

are open, and the circuits through the magnets of the transmitter T_1 and repeating sounder $R\ S$ are closed. The western circuit is open at a and local circuits are open at m, f, d, and m_1. The eastern circuit, which is open at the distant eastern station, is closed at a_1, and local circuits are closed at f_1 and d_1. See Fig. 16 and Art. **44.**

(31) On all submarine cables, on polar duplex, quadruplex, and Wheatstone automatic systems, and more or less on simplex land circuits throughout Europe.

(32) A polarized relay is one that requires the direction of the current flowing through it to be reversed in order to move the armature from one stop to another. See Art. **52.**

(33) In the Horton repeater, shown in Fig. 17, when the eastern key is open, current is flowing only through the magnets M_1 and T. Circuits are open at the repeater at f_1, d_1, and a_1 and closed at f, d, and a.

(34) When the capacity of the artificial line has been so adjusted that it is equal to the capacity of the line and, furthermore, when it charges and discharges at exactly the same rate as the line, a static balance is said to have been obtained. See Art. **120.**

(35) See Art. **136.**

(36) (*a*) Resistances, called retarding coils, may be connected in series with the condenser, one terminal of the condenser being connected to the ground and one terminal of the retarding coil to the line side of the rheostat. Another way is to connect the condenser to some point in the artificial-line rheostat instead of connecting it through a separate retarding coil. See Arts. **88** and **89.**

(*b*) The static balance in the first arrangement is obtained by adjusting the capacity of the condenser and the amount of resistance in the retarding coils; in the second arrangement, by adjusting the capacity of the condenser and the position of the point in the rheostat to which the condenser is joined. See Arts. **88** and **89.**

(37) (*a*) and (*b*) See Art. **95.**

(38) See Art. **96.**

(39) (*a*) The polar duplex is superior to the Stearns duplex because a polarized relay is more efficient and satisfactory than a neutral relay, especially in wet weather when leakage is troublesome. Moreover, on account of using currents that flow alternately in opposite directions, there should be less trouble due to the electrostatic capacity of the line wire. See Arts. **53** and **97.**

(*b*) The essential feature of the polar duplex is the differentially wound polarized relay. Since a polarized relay is used, a pole changer is consequently a necessity.

(40) (*a*) A continuity-preserving pole changer is preferable to one that opens the circuit in the act of reversing the direction of the current because in multiplex systems it is an advantage to preserve an uninterrupted path to the ground at the home station. This reduces what might otherwise cause an interruption in the signals coming from the distant station.

(*b*) Because the continuity-preserving pole changer would connect two dynamos in series through a comparatively small resistance and cause severe sparking at the contact points of the pole changer, when, as usual, machines of rather high voltage are required for duplex and quadruplex circuits. This severe sparking would very soon injure the contact points of the pole changer and put it in an unworkable condition. See Art **112.**

(41) Where dynamos are used, the same machine supplies all circuits requiring the same polarity and about the same electromotive force; hence, where more than one line is supplied from the same machine, it is not practicable to reverse the direction of the current from one machine through one line without also reversing the current in the other lines. Batteries can readily be reversed, because a separate one is used in each line circuit, but a separate

dynamo must be used for each polarity, although one dynamo usually supplies current for a large number of lines. The positive pole of one machine and the negative pole of the other machine are permanently grounded, and the line is shifted from one pole of one machine to the opposite pole of the other machine when it is desirable to reverse the direction of the current in the circuit.

(42) (*a*) The ground coil is a resistance that is cut into the circuit to replace the transmitting apparatus and battery or dynamo when the system is being balanced.

(*b*) It is equal to the resistance of the circuit through the transmitting apparatus and the dynamo or battery to the ground. Where batteries are used, this resistance is practically equal to the internal resistance of the whole battery; and where dynamos are used, it is practically equal to the non-inductive resistance connected directly in series with the dynamo.

(*c*) It is used when the system is being balanced in order to keep the resistance of the circuit to the ground the same whether the transmitting apparatus and the battery or dynamo are cut in or out of the circuit.

(43) (*a*) The receiving circuit includes all apparatus and branch-office lines that may be connected through and controlled by the armature of the polar relay or the repeating sounder that is, in turn, controlled by the neutral relay. It is, consequently, a circuit including all the instruments that are controlled by the motions of the armature of either relay. Messages received on the relay are therefore repeated by all instruments connected in the receiving circuit.

(*b*) The sending circuit includes all instruments and branch-office lines that are connected in series with the magnets of the pole changer or transmitter; hence, the operation of a key anywhere in this circuit will operate the pole changer or transmitter, as the case may be, thus sending the message through the multiplex system to the distant office.

(44) *First*, to center the armature of the polar relay. *Second*, to obtain a resistance balance. *Third*, to obtain a static balance. *Fourth*, to adjust the pole changer.

(45) (*a*) To so adjust the position of the armature that it will remain against either stop or move with equal force from the middle position toward one side or the other. This is done so that the permanent magnetism will pull the armature with equal force from the center position toward either side.

(*b*) See Art. **120.**

(46) When the artificial line has been adjusted so that its resistance is exactly equal to that of the line, a resistance balance is said to have been obtained. See Art. **120.**

(47) By the neutral relay, because it is the instrument that is apt to give the most trouble. If a balance is based on the action of the polar relay, it may prove to be a false one when tested by the neutral relay; whereas, a balance based on the neutral relay will generally prove correct when tested by the polar relay.

(48) (*a*) The bridge duplex requires more battery power than the differential duplex to produce the same strength of current in the distant relay.

(*b*) The bridge duplex is superior to the differential duplex in that it requires less condenser capacity in the artificial lines, and the resistances and condensers can be more readily adjusted to suit the varying conditions of the line.

(49) All batteries or dynamos for supplying current to the main-line circuit are located at one end. No batteries or dynamos are required at the other end, except for the operation of the local receiving and sending circuits.

(50) A continuity-preserving pole changer is a device for reversing the direction of the current in a circuit without opening the circuit.

(51) The trouble would most likely be found in a defective or improperly adjusted transmitter, dirty contact points, a defective leak coil, or a loose connection of the wire attached to the leak coil at the distant station.

(52) By the diplex system. One message is sent by operating a pole changer that controls the direction of the current, and is received by a polar relay at the distant station. Another message is sent by operating a transmitter that controls the strength of the current. The transmitter is located at the same station as the pole changer. The message sent by means of the transmitter is received at the distant station by a neutral relay.

(53) (*a*) See Art. **162.**

(*b*) No. 1 is the polar and No. 2 the neutral, or common, side.

(54) It is advantageous in that it tends to force more of the incoming current through the artificial-line coils of the relays to ground, and it allows the strength of current to be made more nearly the same on short and long lines that are supplied with current at the same potential. On the other hand, a higher potential is required than would be necessary without it in order to give the same current in the short line circuit.

(55) (*a*) and (*b*) See Art. **162.**

(56) The resistance and total current supplied by the dynamos remain constant in all positions of the keys, but two resistances and the transmitter are so arranged that in one position of the transmitter, enough current is shunted to the ground so that the proportion of the total current that passes through the line is only $\frac{1}{3}$ or $\frac{1}{4}$, as the case may be, of what it would be in the other position of the transmitter. See Fig. 61 and Arts. **176** to **183**, inclusive.

(57) Four dynamos are used, two of one electromotive force, say 135 volts, and two of another, say 375 volts. The negative brush of one and the positive brush of the other

of the 135-volt dynamos, and the negative brush of one and the positive brush of the other of the 375-volt dynamos are permanently grounded. Then, by means of a special pole changer, two wires that run to the transmitter are connected in the closed position of the pole changer, as follows: One wire to the ungrounded positive brush of the 135-volt dynamo and the other wire to the ungrounded positive brush of the 375-volt dynamo. When the pole changer opens, the two wires are shifted to the ungrounded negative poles of the other two machines. The transmitter when closed connects one of the two wires mentioned to the line and when open it connects the other wire to the line. Thus, the pole changer controls the direction of the current flowing toward the transmitter, and the transmitter the strength of the current flowing toward the relays and line. See Art. **201.**

(58) Two machines of the same voltage but opposite polarity are used. Three resistance coils and one side of a double transmitter are so connected with the ungrounded terminal of the dynamo and to one wire leading to the pole changer as to cause only $\frac{1}{3}$ (or $\frac{1}{4}$ if the ratio is 1 to 4) as much current to flow toward the pole changer in the open as in the closed position of the transmitter. One side of the double transmitter controls the strength of current from the positive machine, the other side controls the strength of current from the negative machine. The pole changer merely shifts the line from one to the other of the two wires that connect through opposite ends of the double transmitter with the resistances and the dynamos of opposite polarity. See Fig. 75 and Art. **222.**

(59) Multiplex telegraphy is the transmission of two or more messages over the same wire at the same time.

(60) (*a*) As each circuit in a repeater is closed, a short delay occurs in the transmission of a message, for each armature moves over a short distance before the circuit is complete. This shortens the dots and dashes in proportion

to the number of contacts to be closed, and thus the dots are sometimes wholly lost. Therefore, in operating such a circuit, the dots and dashes should be made longer, or, as operators term it, the "sending should be heavy."

(*b*) By sending "heavy."

(61) (*a*) See Art. **73.**

(*b*) On changes both in the direction and in the strength of the current.

(*c*) One key at each end of the line governs the direction of the current, and the other key its strength. At each end there are two differentially wound relays, one of which (the neutral relay) is operated only by the changes in the strength of the current, while the other (the polar relay) is operated only by the changes in the direction of the current. The key at one end governing the strength of the current, therefore, produces at the other end no effect on the polar relay, because the latter responds only to changes in the direction of the current, but this key does operate the neutral relay because the latter responds to changes in the strength, but not to changes in the direction, of the current. Similarly, the key governing the direction of the current operates only the polar relay at the other end because the latter is affected by changes in the direction of the current. The home relays are not operated by the home keys because both relays are differentially wound.

(62) See Art. **251.**

(63) See Art. **259.**

(64) Messages are sent from the battery station to the distant station by the operation of a pole changer, a polarized relay being used at the distant station for receiving these messages. Messages are sent from the distant to the battery station by the operation of a transmitter that increases and decreases the resistance of the line circuit so as to decrease and increase the current in the ratio of 1 to 4.

These messages are received at the battery station on a specially connected double-wound neutral relay.

(65) See Art. **253.**

(66) The space between the armature and the left-hand magnet should ordinarily be at least twice as great as that on the right. The adjustment of the retractile spring is identical with that of an ordinary neutral relay. See Art. **191.**

(67) They are polarized instruments and no springs whatever are used. They are held open by a current that always flows through one winding on the cores. When the key is closed, a current twice as strong circulates in the opposite direction around the cores in a second and distinct winding. Hence, the magnetizing effect of the first current is not only neutralized, but the cores are magnetized just as strongly in the opposite direction. See Arts. **218** and **219.**

(68) Centering the polar armature, obtaining a resistance balance by means of the polar relay, obtaining a resistance balance by means of the neutral relay, obtaining a static balance, and adjusting the neutral relay for incoming signals.

(69) See Art. **274.**

(70) In the closed position of the transmitter in Fig. 75, the resistance in the circuit consists of 267 ohms in the coil C and a combined resistance of 900 ohms in the line and artificial line. This added to 267 ohms gives 1,167 ohms; hence, the current in the circuit will be $\frac{220}{1,167} = .18852$ ampere, or 188.52 milliamperes. Half of this, that is, 94.26 milliamperes, will flow through the line. When the transmitter is open, the coil C will be on open circuit and the current from the dynamo will divide at the point f, part going toward the relays and line and part through the coil A to the ground. The resistance of the circuit from the point f

to the ground now consists of three branches, one through A of 400 ohms, one through the line of 1,800 ohms, and one through the artificial line of 1,800 ohms. The combined resistance of these three paths will be $\frac{900 \times 400}{900 + 400} = 277$ ohms. This is in series with the coil B containing 800 ohms; hence, the total resistance of the circuit is $277 + 800 = 1{,}077$ ohms. The total current is $\frac{220}{1{,}077} = .20427$ ampere. This current will divide through the various branches that start at the point f inversely as their resistances. Hence, we have the proportion: the sum of the currents in the line and artificial-line circuits is to the total current (.20427), that is, the sum of the currents in all the branch circuits, as the combined resistance of all the branch circuits (277) is to the combined resistance of the line and artificial-line circuits (900). From this we get $.20427 \times \frac{277}{900} = .06287$ ampere, or 62.87 milliamperes. One-half of this, or 31.435 milliamperes, will flow through the line. From this it is evident that closing the transmitter increases the current in the line from 31.435 to 94.26 milliamperes, giving therefore a ratio of 1 to 3 almost exactly. See Art. **224.**

(71) See Art. **227.**

(72) See Art. **258.**

(73) To loose connections, broken wires, defective batteries, punctured condensers, defective resistance boxes, defective or improperly adjusted instruments, and the bad condition of the various contact points.

(74) When the transmitter (see Fig. 61) is open, the total resistance of the circuit with the values given in this question is $600 + 1{,}800 + \frac{900 \times 800}{900 + 800} = 2{,}823$ ohms. The total current is $\frac{220}{2{,}823} = .07793$ ampere. Since the line and artificial line whose combined resistance is 900 ohms is in

parallel with the 800 ohms in the leak coil, then the sum of the currents in the line and artificial line will be to the total current supplied by the dynamo (.07793) as the combined resistance of these three branch circuits $\left(\frac{800 \times 900}{800 + 900} = 423\right)$ is to the combined resistance of the line and artificial line (900) That is $x : .07793 = 423 : 900$; hence, the current in the line when the transmitter is open is $\frac{1}{2}\left(\frac{.07793 \times 423}{900}\right) = .01831$ ampere. When the transmitter is closed, the total resistance of the circuit is $600 + 900 = 1{,}500$ ohms. Then, the total current is $\frac{220}{1{,}500} = .14667$ ampere The current in the line when the transmitter is closed is $\frac{.14667}{2} = .07333$. Hence, the ratio of currents in the line in the open and closed position of the transmitter, 18.3 and 73.3 milli-amperes, respectively, is very nearly 1 to 4.

(75) See Art. **260.**

(76) First suspect an improperly adjusted pole changer at the distant office; if that is not the cause, suspect the distant battery.

(77) (*a*) See Art. **271.**

(*b*) See Art. **272.**

(78) See Arts. **252** and **253.**

(79) (*a*) See Art. **123.**

(*b*) The tension of the spring must not be too great; the trunnion must not be too tight; and the local battery, and, consequently, the tension of the spring, must not be too weak See Art. **122.**

(80) (*a*) See Art. **263.**

(*b*) See Art. **263.**

(81) (*a*) The station possessing the normal ground would find his apparatus out of balance. See Art. **276.**

(*b*) See Art. **276.**

(*c*) See Arts. **277** and **278.**

(82) See Art. **264.**

(83) It would be impossible to obtain a resistance balance. See Art. **275.**

TELEGRAPHY.

(PART 5.)

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(1) The polar relay of one set is arranged to control the pole changer of a second set, and the polar relay of the second set is arranged to control the pole changer of the first set. See Arts. **1** and **2** and Figs. 1 and 2.

(2) When dynamos are used, the proper current is obtained by inserting the proper amount of resistance (lamps or coils of German silver) in the circuit; but when primary cells are used, the proper current is obtained by using just enough cells.

(3) The repeating sounder on the common side of one set may be arranged to control the transmitter on the common side of the second set, and the repeating sounder of the second set, to control the transmitter of the first set. On the polar sides, the polar relay of the first set controls the pole changer of the second set, and, similarly, the polar relay of the second set controls the pole changer of the first set. Or, the repeating sounder on the common side of the first set may be arranged to control the pole changer of the second set, the polar relay of the second set controlling the transmitter of the first set; similarly, the repeating sounder on the common side of the second set controls the pole changer of the first set, and the polar relay of the first set controls the transmitter of the second set.

(4) The magnets in all local circuits are wound to 20 ohms, the resistance of all local circuits, including branch-office loops, are brought up to 100 ohms by means of the resistance coils and the local sounder, and the branch-office loop circuits are connected in parallel with the main-office circuits instead of in series, as is usually the case in other offices. In connection with each polar duplex or one-half of a quadruplex set, there are upon the desks two single-pole, double-throw, knife switches, which, in connection with the loop spring jacks and wedges, enable the chief operator to include a branch-office loop in the local circuit of a set or to connect the two sets so that they may repeat into one another Each half of a quadruplex or repeater set is treated as a duplex set. See Arts. **5, 6,** and **7.**

(5) One advantage of this system over the Morse system is that it is less likely to be affected by ordinary trouble on the wire, and it will work readily across heavy escapes, and even when the wires are crossed or grounded, including the wire upon which the phonoplex is working. Furthermore, even bad weather fails to affect the signals to any great extent. A disadvantage of the system is the fact that only one phonoplex circuit can be worked successfully at the same time upon the same line of poles carrying a number of wires. A companion phonoplex on a line of poles on the opposite side of a railroad track may even be impracticable, for the reason that the phonoplex impulses are so penetrating that their inductive effects extend far into the space around the wire.

(6) A multiplex single-wire, or defective-loop, repeater is an arrangement of apparatus whereby a single branch line (usually a city branch-office line) may be so connected to a duplex or one side of a quadruplex set that the messages passing over the multiplex system may be sent over the branch line, and so that the branch office may send through the multiplex apparatus to the distant multiplex station. See Arts. **9** and **10.**

(7) The siphon is made to vibrate to and from the paper, in order to avoid the friction between the end of the siphon and the paper tape, which would impede the movement of the delicately suspended coil. Thus the siphon traces a dotted, instead of a continuous, line. The vibration of the siphon is also necessary because otherwise the ink is liable to gather upon the end of the siphon in globular form, and either blur the record or cause it to stop recording.

(8) The Hurd branch-office signaling device, as shown in Fig. 17, may be used. In this method an annunciator, connected to the branch-office wire, is so arranged that the shutter will fall and ring a bell if the branch-office operator momentarily grounds his line at the proper place by a switch provided and properly connected for this particular purpose.

(9) (*a*) Two line wires are used. The two line wires are used as a complete metallic circuit for telephonic communication and each wire with the earth as a return path constitutes one telegraph circuit. Thus the two line wires, with the earth as a common return path for both, provide two distinct and separate telegraph circuits.

(*b*) If only one wire is used, then one telegraph and one telephone message may be sent simultaneously. In this case, the earth is used as a common return path for both the telephone and telegraph currents.

(10) The siphon is made to vibrate by arranging the apparatus so that pulsatory currents are sent through an electromagnet. The frequency of these pulsations is made to coincide with the natural rate of vibration of the siphon. The lower end of the glass siphon has glued to it a minute piece of iron that the electromagnet, over which the paper tape passes, attracts every time a pulsatory current passes through the magnet. The pulsatory currents are caused by a reed and magnet, arranged in a manner similar to a vibrating bell. The rate of vibration of the reed is adjusted

to suit the natural rate of vibration of the siphon by regulating the height of a column of mercury in a glass tube attached to the reed. See Art. **87.**

(11) It is a combination of resistances and condensers so arranged that the artificial cable has not only the same resistance and capacity as the real cable it is intended to resemble, but it also charges and discharges at the same rate as the cable.

(12) (*a*) Two line wires are connected at each end through a high impedance coil. A telegraph set is connected between the center of each coil and the ground at each end, and the telephones at each end are connected directly across the two line wires. Hence, the two line wires form a complete metallic circuit for the telephones, and the impedance coils at each end prevent the passage of the telephone currents through them from one line to the other. The two line wires in parallel form one path (having only one-half the resistance of one line circuit), and the ground the other path for the telegraph current. At each end one-half of the impedance coil is in series with each line wire, and, hence, the two halves of the impedance coil at one end are in parallel with each other so far as the telegraph current is concerned, but in series with each other so far as the telephone current is concerned. Hence the impedance coil at each end offers only one-half the resistance of one-half of the whole coil (that is, one-fourth the resistance of the whole coil) to the telegraph current, and, moreover, the telegraph current does not produce any magnetism in the iron cores of these coils, because an equal current flows in each coil in opposite directions around the iron core. See Art. **65.**

(*b*) Two messages, one telephone message using the two line wires as a complete circuit, and one telegraph message using the two line wires in parallel as one path and the ground as the return path of the circuit. See Art. **64.**

(13) It is a multiplex single-wire, or defective-loop, repeater.

(14) The bridge duplex method. In the Muirhead double-block system, the resistances in two branch arms are replaced by condensers.

(15) (*a*) It is a multiplex single-wire, or defective-loop, repeater.

(*b*) It depends on the Toye-repeater principle, that is, on the substitution of a resistance in place of the branch-office line circuit when the repeating transmitter opens.

(16) A coil having considerable self-induction is included in the line circuit. Across the terminals of this coil is a local circuit including, say, merely a key and a battery. Whenever this local circuit is broken, the high self-induction of the magnetic coil sets up an impulse that travels over the line. This impulse causes the phone, which resembles a telephone receiver, to give out a sound resembling the click of a telegraph sounder. The closing of the local circuit does not affect the telephone; it is affected only by the opening of the local circuit. The noise produced by the down stroke of the sounder is imitated by breaking a strong current and the up stroke of the sounder is imitated by breaking a somewhat smaller current. See Arts. **72**, **73**, and **74**.

(17) (*a*) Not usually.

(*b*) Because the resistance of a main line is usually at least an appreciable part of the total resistance of the circuit; hence, any change in the line resistance due to a change in the weather would usually require a readjustment of the resistance in the Moffat repeater, or of the number of extra cells in the Downer repeater.

(18) The message is first punched in a paper tape by a machine called a perforator; the punched paper is then fed through a transmitter, and at the distant end is recorded in ink on a paper tape in the dot-and-dash characters of the regular telegraph code; an operator then translates the code record and writes the message on an ordinary message blank with or without a typewriter.

(19) (*a*) The accuracy and speed of working is very much better when automatic transmission is used in place of hand or manual transmission.

(*b*) The Cuttriss and the Crehore and Squier sine-wave transmitters.

(20) The Downer repeater depends on the principle of including an extra battery in the higher resistance circuit, so as to keep the current strong enough to hold closed the transmitter through the contacts of which the circuit that happens to be sending passes.

(21) The Half-Milliken repeater is used when it is necessary to connect a polar duplex or one side of a quadruplex set with a main line, so that the distant end of this main line may both send and receive (not simultaneously, however) through one wire from the repeater set.

(22) All the circuits are normally closed in the Half-Milliken repeater.

(23) By using condensers in the circuit at each end somewhere between the ground and the cable.

(24) By this repeater, a branch-office loop may be connected in circuit with a quadruplex set in such a manner that the two main terminal offices may work single and the branch office will be able to hear and to break, when necessary, either main terminal office that may be sending. The two ends can send double, that is, simultaneously, if it is not desired to send the messages to the branch offices. Furthermore, the branch office can send to the repeating office and to either main terminal office, in which case the line is worked single. See Arts. **26** to **29.**

(25) One key only need be placed between the ground and the two branch-office circuits. See Arts. **30, 31,** and **32** and Fig. 12.

(26) A double-loop repeater is an arrangement of apparatus that enables two branch offices to receive a message

that comes to one main office over a multiplex system from another main office, and it also allows either branch office to send to the other branch office and through the sending side of the multiplex set at the nearer main office to the distant main office.

(27) The key at station *A* must remain closed. Then, if *B* sends, the repeating sounder RS_3 will operate the pole changer of the set *C*; and if *C* sends, the repeating sounder RS_4 will operate the pole changer of the set *B*. Hence, messages may be both sent and received at both stations *B* and *C*. Confused signals, due to the sending at both *B* and *C*, will pass through the pole changer of the set *A*; hence, neither message can be read at *A*. See Arts. **38** to **41**.

(28) The contacts of the repeating transmitter may become dirty or corroded, the repeating transmitters may be improperly adjusted, and the current through the pole changer or transmitter magnet of the multiplex set may not be the same, as it should be, in the two positions of the repeating transmitter.

(29) This arrangement allows any one of the three stations to use the line as a simplex system, to send to the other two, and, moreover, allows any two to work double, that is, duplex, provided the key at the third station is kept closed.

TELEGRAPHY.

(PART 6.)

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(1) See Arts. **297** and **298.**

(2) It is a system developed by Crehore and Squier, in which an alternating sine-wave current is used. The circuit is never opened or closed except when the sine-wave curve is passing through its zero value. A telegraph code is arranged by holding the circuit open for the duration of one or more half or full current waves, and then closing the circuit for one or more half or full waves. See Arts. **172** to **175.**

(3) A perforated tape, the holes in which represent the message, is first prepared by means of three keys, one representing dots, the second spaces, and the third dashes. The depression of the dot key causes an electromagnet to punch a hole in the tape on one side of the center line and advances the tape a definite distance; the depression of the dash key produces a similar hole on the other side of the center line and advances the tape the same distance as the other key; the space key advances the tape the necessary distance between the letters. The tape is then fed through a transmitting device, the holes on one side causing positive-current impulses and the holes on the other side negative-current impulses to be sent over the line. At the receiver the dot, or positive, impulses produce a mark along the center of a chemically sensitized tape, while the dash, or negative, impulses produce two parallel marks along the tape, one on each side of the center line. These are translated and

written out on a message blank with or without a typewriter. The process is the same as in the Wheatstone automatic system, but it is capable of transmitting messages at a very much higher speed. See Arts. **160** to **166.**

(4) (*a*) The Thomson, or reflecting, galvanometer and the D'Arsonval galvanometer.

(*b*) The Thomson galvanometer is by far the most sensitive and, therefore, suitable where tests of the greatest accuracy are to be made. It, however, has the disadvantage of being affected by slight external magnetic disturbances. The D'Arsonval galvanometer is the most satisfactory instrument for general use. It is sufficiently sensitive for all practical purposes, and is not affected by external magnetic fields. The suspension of the needle is not so delicate as in the Thomson, thus making it easier to set up and less liable to injury.

(5) One serious objection charged against wireless telegraphy is the fact that with the method generally used at present, two independent communications cannot be received at the same station readily, if at all; and every receiver placed within the radius of action of a transmitter is acted upon by the waves sent out by the one transmitter. Hence, if two transmitters are simultaneously operated, complete interference or a confusion of the two sets of signals is the result. A second serious objection or defect is the comparatively short distance over which it may be worked. Up to March, 1901, the longest distance across which telegraph signals had been successfully sent was 200 miles over water and much less over land. Both of these objections may, of course, be more or less overcome in the future.

(6) They enable the sending over one wire of from 3 to 20 times as many messages as could be sent in the same time over a simple circuit by hand. On the other hand, they are more complicated than the Morse key-and-sounder method, and the various steps through which the message passes increase the probability of making mistakes.

(7) A coherer is a device for detecting the presence of electromagnetic waves. It is sensitive to electromagnetic waves, because the latter cause the resistance of the coherer to decrease enormously.

(8) A perforated tape representing the message must be prepared; this tape must then be fed through the transmitter. In the first method described, the signals are received in zigzag lines on sensitive photographic paper. The photographic paper must be developed and then the zigzag code message translated and written on a message blank. In the writing telegraph system, the message is received in a rather stilted form of writing on a sensitized sheet of photographic paper that must be developed.

(9) The objections are about the same as to all automatic telegraph systems, namely, the complication of the apparatus and the several steps through which the message must pass, and there is also the serious objection to the additional complication rendered necessary by the use of the sensitized photographic paper.

(10) See Arts. **280** and **281.**

(11) A deflection is first obtained through a known resistance with a given battery, and from this the constant of the galvanometer is computed. After this, the deflection produced by a current from the same battery through the insulation resistance to be measured is noted, and by comparing this deflection with that through the known resistance, due allowance being made for the galvanometer shunts that are used, the insulation resistance may be computed. See Arts. **287** to **290.**

(12) See Art. **306.**

(13) (*a*) See Art. **274.**
(*b*) See Art. **275.**

(14) $342 \times 1{,}000 \times \frac{1}{10} = 34{,}200$.

(15) The Wheatstone bridge.

(16) See Art. **290.**

(17) Because the electrostatic capacity of long circuits is frequently high enough to allow enough current to pass into and out of the circuit to ring the polarized bell of the testing set, thus producing the same effect as if the circuit were continuous, or as if a ground or cross existed

(18) By substituting in formula **17,** in which $R = 515.58$, $m = 1{,}000$, $n = 1{,}000$, and $p = 2{,}015$ ohms, we get as the resistance along the bad line to the fault

$$x = \frac{1{,}000 \times 515.58}{1{,}000 + 1{,}000 + 2{,}015} = 128.4 \text{ ohms.}$$

Then, the distance to the fault in feet from the testing station equals

$$\frac{128.4 \times 1{,}000}{2\ 578} = 49{,}806 \text{ ft., or } 9.43 \text{ mi. Ans.}$$

(19) Call the first measurement, which gave 1,077 ohms, a; the second 1,130 ohms, b, and the third 1,184 ohms, c; then, substituting these values in formulas **4, 5,** and **6,** we get

$$\text{Resistance of line } x = \frac{1{,}077 + 1{,}130 - 1{,}184}{2} = 511.5 \text{ ohms.}$$

$$\text{Resistance of line } y = \frac{1{,}077 + 1{,}184 - 1{,}130}{2} = 565.5 \text{ ohms.}$$

$$\text{Resistance of line } z = \frac{1{,}130 + 1{,}184 - 1{,}077}{2} = 618.5 \text{ ohms.}$$

Ans.

(20) The insulation resistance per mile is found by multiplying the total insulation resistance found from the measurement by the length of the line in miles, or by multiplying by the length of the line in feet and dividing this result by 5,280 (the number of feet in 1 mile).

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NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Balancing cable 6 92" means that balancing cable will be found on page 92 of section 6.